The Observant Computer ▪ Rocket Planes ▪ Life Made to Order

MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

APRIL 2003

WWW.TECHNOLOGYREVIEW.COM

SURVEILLANCE NATION

IT'S COMING— AND YOU JUST MIGHT LIKE IT

USA $4.99 • CANADA $6.99

04

0 09281 01308 2

PLUS: Paperless Medicine ▪ Fixing Software ▪ Nano Toxins


we see
the toughest reservation in town.
Where there are big ideas but still small budgets, we see opportunities for success. That's what inspires us to create software that helps small businesses start, grow, and thrive. Even the smallest companies get a chance to compete on today's tech-driven playing field. microsoft.com/potential
Your potential. Our passion.
915
B
Specials
Microsoft®

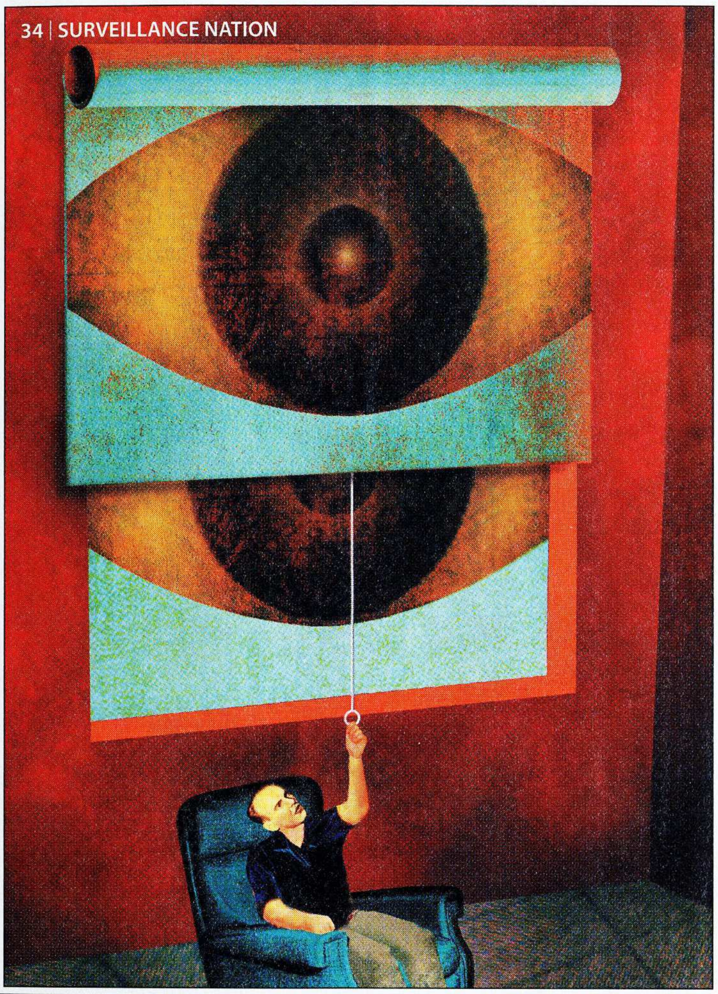

STRO
919
© 2003 Microsoft Corporation. All rights reserved. Microsoft is a registered trademark of Microsoft Corporation in the United States and/or other countries.

I AM A SHELL.

I CAN FIGHT CANCER. I AM *MERCENARIA MERCENARIA*. I HAVE AN EXTRACT IN MY SHELL THAT HAS THE POWER TO SLOW CANCERS IN MICE. I HAVE THE POWER TO BE THE NEXT PENICILLIN. I AM MORE THAN A SHELL.

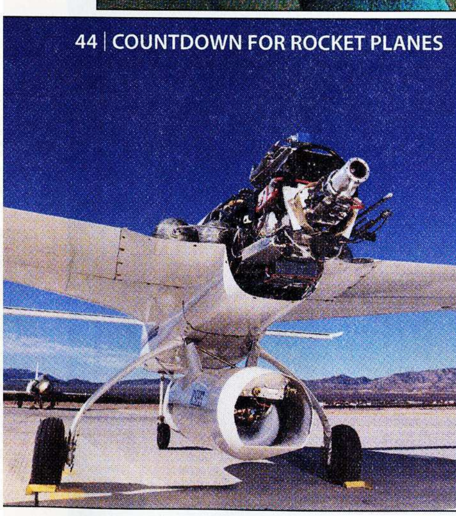
CONTENTS

TECHNOLOGY REVIEW VOLUME 106, NUMBER 3

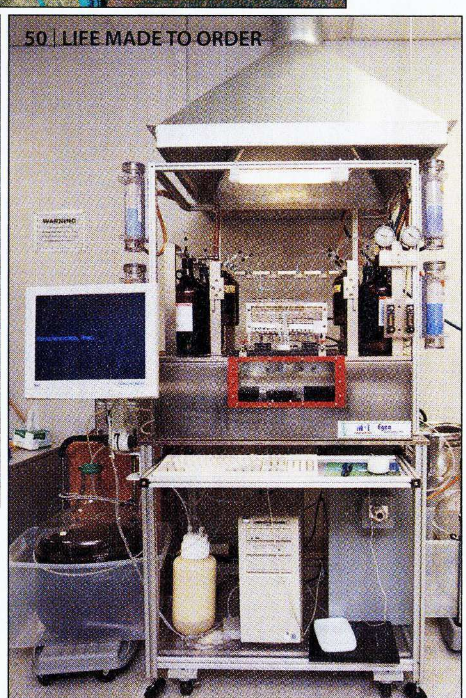


34 | SURVEILLANCE NATION

April 2003



44 | COUNTDOWN FOR ROCKET PLANES



50 | LIFE MADE TO ORDER

CONTENTS

TECHNOLOGY REVIEW VOLUME 106, NUMBER 3

26 | INNOVATION

18 | PROTOTYPE

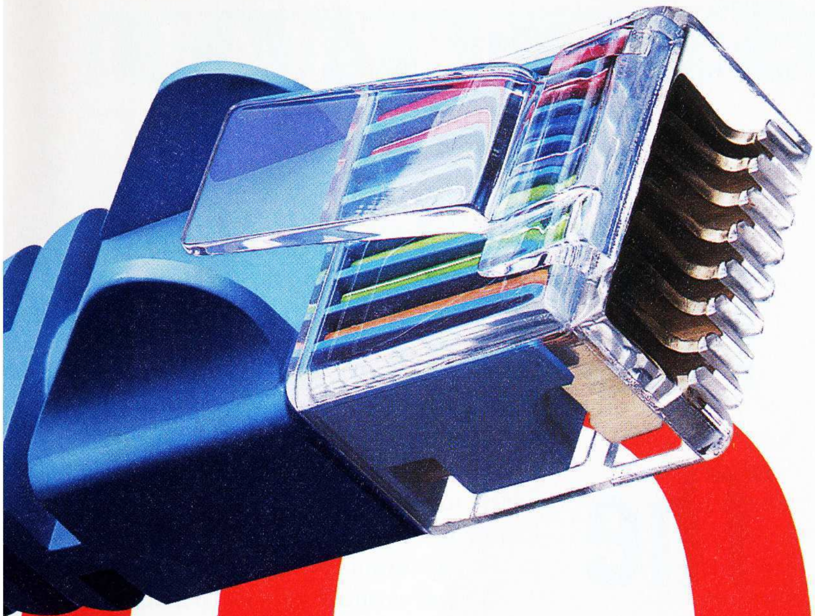
80 | TRAILING EDGE

DEPARTMENTS

COLUMNS

New York Institute of Technology's fiber optic network
the most of it, NYIT graduated to Xerox multi-

Learn more: www.xerox.com/learn **For a sales rep: 1-800-ASK-XEROX ext. LEARN**



KEYNOTE
Michael Dell, Founder and CEO, Dell Computer Corporation

KEYNOTE
Jeffrey R. Immelt, CEO and Chairman, General Electric

TR100 HOST
Bob Metcalfe, Founder, 3Com Corporation, Venture Partner, Polaris Venture Partners

MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

The Emerging Technologies Conference at MIT

ETC2003

2003 Symposium and TR100 Awards Ceremony

Sept. 24-25, 2003

Kresge Auditorium, MIT Campus, Cambridge, MA

Technology Review Magazine presents a rare opportunity to spend two days with the most brilliant minds in a host of emerging technologies. Cutting through the clutter, this conference will examine the most promising and impactful breakthroughs in technology and industry. How each works, what it means to the current business landscape, market potential, key players, regulatory issues, who stands to win/lose, and where stumbling blocks remain. In just two days, you will gain a detailed understanding of what's truly important and why. **The Emerging Technologies Conference at MIT** also offers an invaluable networking event, which brings together key players from the technology, engineering, investment and management communities.

PRODUCED BY:

Penton
TECHNOLOGY & LIFESTYLE MEDIA

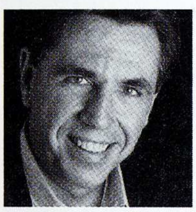
For details visit www.etc2003.com. Contact vcaprio@penton.com for sponsorship opportunities.

OUR SURVEILLANCE NATION

Big Brother is watching you. So are little sister, the neighbors, your boss, and mom and pop. And it's more and more likely that you're watching them too.

If there's a message to this month's cover story on our transformation into a surveillance society, it's that we are all responsible.

It is precisely this mass participation in surveillance—along with the difficulty of assigning sole responsibility to insidious corporate and government entities—that makes this story so compelling. Even more compelling—and sobering—is that we are losing our privacy not for some nefarious purpose but for the best of reasons: safety, security, and generally improved quality of life. Indeed, surveillance cameras in public spaces, parking garages, and around our neighborhoods can deter crime and speed its solution. Cameras keep tabs even on the police themselves—helping avert the next Rodney King incident. Video cameras, linked to the Web, let us check traffic, and they offer the peace of mind that comes from seeing our kids having fun at home or preschool while we're at work. And video cameras are just the most conspicuous component of the rapidly propagating surveillance infrastructure: at more and more schools, Internet usage is monitored to ensure students don't visit pornography sites; similar systems watch over employees to guard against illicit actions and possibly against harassment, sexual or otherwise. These and other kinds of monitoring *can* make our lives easier and safer.



And that, ironically, is what makes ubiquitous surveillance so dangerous. We have put ourselves in a position where even though the motivations are good, the outcome could be chillingly bad. Not only governments, but also private groups and individuals, have real opportunities to amass an unprecedented amount of information about each of us—the people with whom we have associated, what we have bought, where we've been, maybe even where we *are*. Such data, gathered for seemingly benign reasons, could nonetheless be used for suppression of free speech, idea control, and (shades of the movie *Minority Report*) to finger people for some future crime—purposes that rumble the foundations of free societies.

The story is so big that *TR* is bringing it to you in two parts. This month's piece covers the total landscape. It opens with routine traffic-watching webcams placed in an area of roadway construction in western Massachusetts; extends to other forms of electronic surveillance for monitoring consumers, employees, and schoolchildren; and ends with the technical dangers—large and small—inherent in massive data-collection and surveillance efforts. Next month's story will focus on what can be done to navigate the perils of this unfolding reality and how technology is central not only to addressing the problem but also to ensuring that the surveillance society is contained.

We are fortunate in having two writers uniquely qualified to tell this story. *TR* contributing writer Charles C. Mann is a well-known journalist whose last piece for us was the July/August 2002 cover story, "Why Software Is So Bad." His coauthor is legendary software engineer Dan Farmer, former chief of network security for Sun Microsystems, Silicon Graphics, and Earthlink. Farmer has advised Congress on privacy and security in the Internet age. But he is best known for authoring, along with Dutch computer scientist Wietse Venema, a controversial program called SATAN, which searched computer networks for security holes and other information. Critics charged that by making SATAN easy-to-use and free to everyone, its authors had given even amateur hackers tools to crack corporate and government networks. Farmer says the program alerted the good guys to a big problem.

But back to that snarled western Massachusetts traffic. The story begins with eight webcams that let motorists and rescue workers check traffic and avoid congestion. But hidden in this network of nicety is a potential catch.... —*Robert Buderi*

MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

EDITOR
Robert Buderi

EXECUTIVE EDITOR	David Rotman
DEPUTY EDITOR	Herb Brody
MANAGING EDITOR	Tracy Staedter
ART DIRECTOR	Eric Mongeon
SENIOR EDITORS	Sally Atwood Wade Roush David Talbot Rebecca Zacks
SENIOR ASSOCIATE EDITOR	Erika Jonietz
ASSOCIATE EDITOR	Megan Vandre
STAFF WRITER	Gregory T. Huang
ASSISTANT ART DIRECTOR	Jamie Kelleher
PHOTO EDITOR	Lisa Petrie
COPY CHIEF	Elyse M. Friedman
FACT CHECKER	Lisa Scanlon
PRODUCTION MANAGER	Valerie V. Kiviat
EDITORIAL ASSISTANT	Alyssa Danigelis
TR100 RESEARCHERS	Margaret Hall Jonathan Skolnick

TECHNOLOGYREVIEW.COM

SENIOR EDITOR	Kevin Hogan
ASSOCIATE EDITORS	David Cameron Alan Leo

CONTRIBUTING WRITERS

Ivan Amato
Jon Cohen
Peter Fairley
David H. Freedman
Simson Garfinkel
Charles C. Mann
Michael Schrage
Evan I. Schwartz
Seth Shulman
Gary Taubes
Claire Tristram
M. Mitchell Waldrop

CUSTOMER SERVICE/SUBSCRIPTION INQUIRIES
NATIONAL: 800-877-5230
INTERNATIONAL: 386-447-6352
www.technologyreview.com/customerservice
Cost $34 per year
Canada residents add $10
Other foreign countries add $30

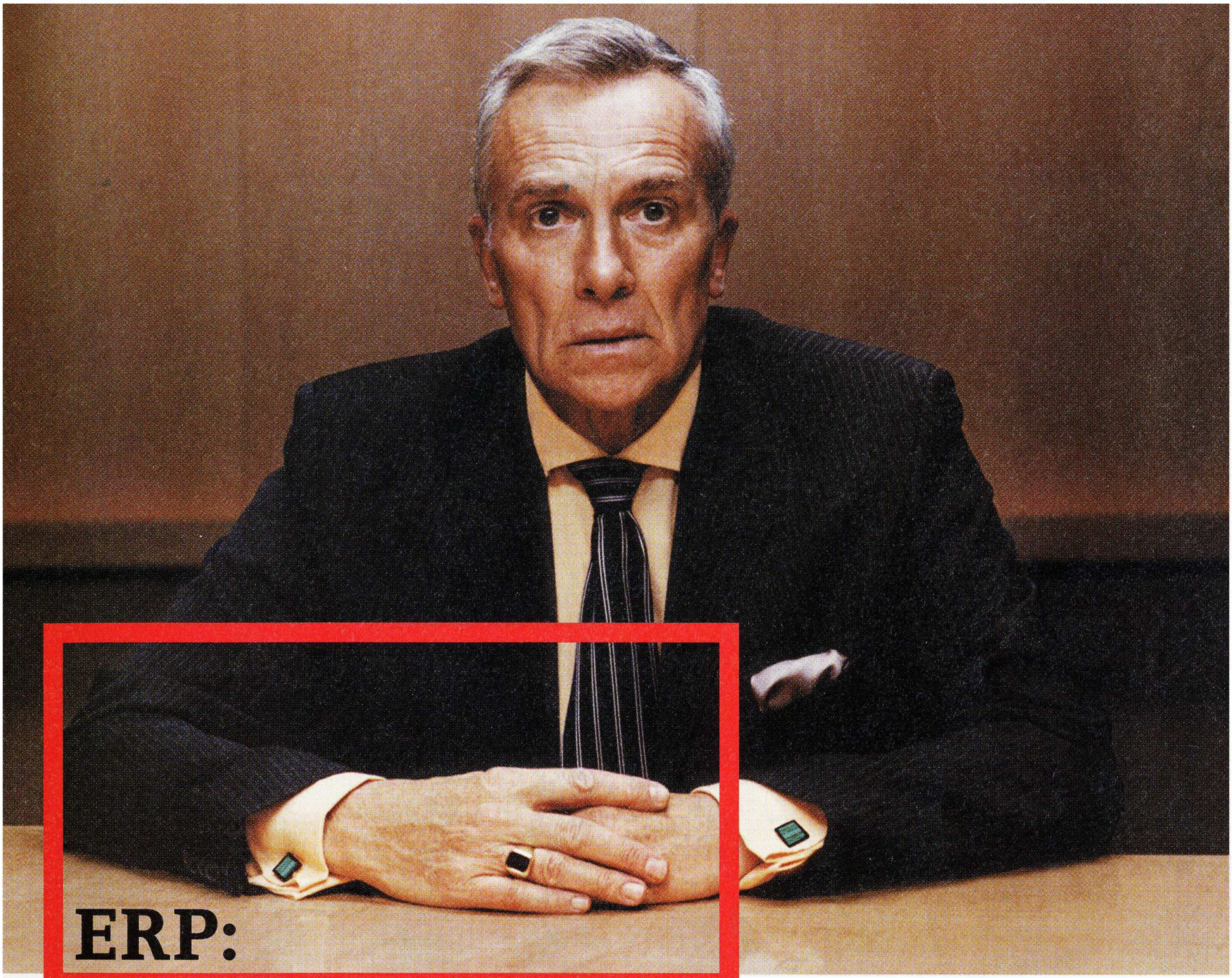
ADDRESS CHANGES
www.technologyreview.com/custserv/addresschange
MIT Records 617-253-8270 (Alums only)

PERMISSIONS
978-750-8400
www.technologyreview.com/customerservice/permissions.asp

REPRINTS
717-399-1900 ext. 118
technologyreview@reprintbuyer.com
or www.technologyreview.com/customerservice/reprints.asp

TR RELAUNCH FUND
MILLENNIAL PATRON
Robert M. Metcalfe
CENTENNIAL PATRONS
Steve Kirsch
DuWayne J. Peterson Jr.

TECHNOLOGY REVIEW
One Main Street, 7th Floor
Cambridge MA 02142
TEL: 617-475-8000 FAX: 617-475-8043
www.technologyreview.com



ERP:

Sound made by CIO when people see data they shouldn't.

Your people need access to information. You just don't want to give everybody access to everything. You need a secure identity management process. Novell's Nsure™ solutions let you control access for all your employees and business partners. Quickly and easily. So you can stop worrying about who's seeing what and start concentrating on more important things, like the bottom line. To learn how Novell's consultants and partners can apply their expertise to help you increase security without decreasing access, call us at 1-800-721-2800 or visit http://www.novell.com/nsure. WE SPEAK YOUR LANGUAGE.

Novell.

▸ SUBSCRIBER SERVICES

IF YOU MOVE
Send us your old and new address or visit **www.technologyreview.com/customerservice**. (Please allow 6 weeks processing time.)

MISSING OR LATE ISSUES
Technology Review is a monthly publication. As a new subscriber you should receive your first issue 4 weeks after your order is placed. If you are an established customer and your copy of *Technology Review* does not arrive within 4 weeks after an issue date, e-mail, telephone or write us. In either case, we'll get to the bottom of the problem and send you the missed issue. Contact us at **technologyreview@palmcoastd.com** or call 800-877-5230.

BACK ISSUES
To order a back issue, please visit our Web site at **www.technologyreview.com/customerservice**. Or send a check or money order for $6.50 to *Technology Review* Back Issues Dept., PO Box 420005, Palm Coast, FL 32142.

ARTICLE REPRINTS (100 OR MORE)
Contact Reprint Management Services at 717-399-1900, sales@reprintbuyer.com or **www.reprintbuyer.com.**

PERMISSION TO PHOTOCOPY
Contact Copyright Clearance Center at 978-750-8400, fax at 978-750-4470, or online at **www.copyright.com.**

PERMISSION TO REPUBLISH
To use an article (text only) or other contents of *Technology Review* in a newsletter, newspaper, brochure, pamphlet, journal, magazine, text or trade book, dissertation, presentation, advertisement, CD-ROM or Web site, please contact Copyright Clearance Center at 978-750-8400, fax at 978-750-4470, or online at **www.copyright.com.**

AN MIT ENTERPRISE TECHNOLOGY REVIEW

MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

PUBLISHER AND CEO
R. Bruce Journey, bruce.journey@technologyreview.com

VICE PRESIDENT AND GENERAL MANAGER
Martha Connors, martha.connors@technologyreview.com

VICE PRESIDENT, SALES AND MARKETING
Kate Dobson, kate.dobson@technologyreview.com

CORPORATE

DIRECTOR OF BUSINESS DEVELOPMENT
J. R. "Matt" Mattox
matt.mattox@technologyreview.com

HUMAN RESOURCES MANAGER
Ann E. Warner

DIRECTOR OF INFORMATION TECHNOLOGY
Lon Anderson

NETWORK COORDINATOR
Scott Hendry

EXECUTIVE ASSISTANT TO THE CEO
Kelli Talbot

OFFICE ADMINISTRATOR
Eileen Cahalane

TECHNOLOGYREVIEW.COM

CONTENT MANAGER
Kristy Robinson

LEAD WEB TECHNOLOGIST
Eric Engel

GRAPHIC DESIGNER
Matthew Bouchard

CONTENT AND TRAFFIC ANALYST
Thomas Pimental

CONTENT ASSOCIATE
Johanna Purcell

SALES AND MARKETING

ASSISTANT TO THE VP, SALES AND MARKETING
Sharon Morani

ADVERTISING SERVICES MANAGER
Amy McLellan
amy.mclellan@technologyreview.com

SENIOR MARKETING MANAGER
Kathleen Kennedy

SALES AND MARKETING ASSOCIATE
Kristen Maloney

CONSUMER MARKETING

DIRECTOR OF CIRCULATION AND CONSUMER MARKETING
Elaine Spencer

ASSOCIATE CONSUMER MARKETING DIRECTOR
Corrine L. Callahan

DIRECT RESPONSE MANAGER
Sharon Maxwell

CONSUMER MARKETING ASSISTANT
Faith Welt

FINANCE

CONTROLLER
John W. Keegan

SENIOR ACCOUNTANT
John F. Leahy

ACCOUNTANT
Letitia Trecartin

INTERN
Walter Rodriguez

ADVERTISING SALES

NEW ENGLAND/BOSTON: 617-475-8004	Paul Gillespie	paul.gillespie@technologyreview.com
MID-ATLANTIC/NEW YORK: 212-419-2820	Alan Levine Mason Wells	alan.levine@technologyreview.com mason.wells@technologyreview.com
SOUTHEAST/NEW YORK: 212-419-2820	Dean Grant	dean.grant@technologyreview.com
SOUTHWEST/DALLAS: 972-625-6688	Randy Artcher Steve Tierney	randy.artcher@tierney.com steve.tierney@tierney.com
MICHIGAN/DETROIT: 248-546-2222	Colleen Maiorana	colleenm@maiorana-partners.com
	Sue Scott	sscott@maiorana-partners.com
MIDWEST/CHICAGO: 312-629-5264	Chris Svoboda	amssvoboda@aol.com
NORTHWEST/SAN FRANCISCO: 415-659-2980	Merrick Musolf Sam Staley	merrick.musolf@technologyreview.com sam.staley@technologyreview.com
SOUTHERN CALIFORNIA/L.A.: 310-451-5655	Gregory Schipper	gschipper@whiteassociates.com
EUROPE: 44-207-630-0978	Anthony Fitzgerald David Wright	afitzgerald@mediamedia.co.uk dwright@mediamedia.co.uk
CHINA, HONG KONG, PHILIPPINES, AND THAILAND: 852-28-38-87-02	Herb Moskowitz	mediarep@netnavigator.com
AUSTRALIA: 61-2-9929-5929	Anton Gruzman	sthpac@ozemail.com.au
TAIWAN: 886-2-25-23-82-68	Keith Lee	leekh@ms4.hinet.net
SOUTH KOREA: 82-27-39-78-40	S.Y. Jo	biscom@unitel.co.kr
JAPAN: 813-3261-4591	Shigeru Kobayashi	shig-koby@media-jac.co.jp
ONLINE ADVERTISING: 212-419-2824	Anne Toal	anne.toal@technologyreview.com

WORLD-CHANGING TECHNOLOGIES

In your article about quantum cryptography ("10 Emerging Technologies That Will Change the World," *TR* February 2003), Nicolas Gisin claims that quantum technology will eliminate the possibility that increasing computer power could be used to crack existing security codes. The amount of computation required to crack a given cipher rises *geometrically* with the number of bits used for the keys, whereas the computer power needed to encrypt and decrypt data depends only *linearly* on key length. If this relationship holds, it doesn't matter how fast computers become; we need only to increase key length. Nevertheless, some particularly clever person could invalidate these assumptions about cracking ciphers. Perhaps that's the risk Gisin strives to protect us from.

Jim Roberts
Wilmington, DE

You credit Nicolas Gisin's team with holding the world's distance record in quantum cryptography on the basis of his transmission of a quantum key through a 67-kilometer length of optical fiber. Mitsubishi Electric recently broke that mark by transmitting a key quantum cryptography key 87 kilometers.

Junichi Kitsuki
Mitsubishi Electric
Tokyo, Japan

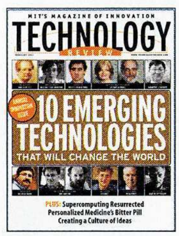
These 10 innovations will not "change the world," or even the Western world, but rather the world of the well-off. More desperately needed are innovations in the legal sphere to give privilege to knowledge sharing over profits, a point that has been made several times in your publication.

Maria Babikova
Tecumseh, Ontario

THE CULTURE OF IDEAS

Thank you, Nicholas Negroponte, for recognizing people like myself for their hard work using all the imaginative powers they can muster to function creatively in everyday society ("Creating a Culture of Ideas," *TR* February 2003). I was not an advanced learner: I had to learn how to think outside the box because I couldn't figure out how to think inside the box. Education is structured to teach the masses, not the individual mind. My fear is that society leaves children behind who have a great deal to offer. These children can provide us with innovative new methods for exploring life and work.

Suzanne Aleva
South Bend, IN



"These 10 innovations will not 'change the world,' or even the Western world, but rather the world of the well-off. More desperately needed are innovations in the legal sphere."

Listening to the young and learning from failures are clearly good ideas, but Negroponte's assertion that this explains the dominance of the United States in Nobel prizes and technical innovation is bizarre. Our technical hegemony is due instead to the massive funding for R&D, education, and infrastructure in academia, industry, and the military, as well as the influx of scientific talent from Europe and Asia. Moreover, Negroponte's statement that "we are uniquely willing to listen to our young" is insulting, implying that Asians, Europeans, and others don't listen to their young. Linus Pauling's advice is much better: "Have lots of ideas, and throw away the bad ones."

Fred Daum
Carlisle, MA

CONTACT US

E-MAIL: letters@technologyreview.com
WRITE: *Technology Review*, One Main Street, 7th Floor, Cambridge MA 02142
FAX: 617-475-8043

- **Please include your address, telephone number, and e-mail address.**
- **Letters may be edited for both clarity and length.**
- **To discuss our articles online, click on Forums at www.technologyreview.com.**

Not in my lifetime has the gulf separating those with experience and those with energy seemed so great. I put this down to what we might call the disintermediation of post-elementary elite education. The old give-and-take bond between professors and students has given way to a more distant, diffuse business. Great men and women pop in for lectures between talk show appearances and consulting gigs, leaving teaching assistants to mark papers. In the process, something unique and valuable has been misplaced, and we fail to alloy the most precious ores to be found at opposite ends of adult life.

Michael M. Thomas
Brooklyn, NY

PERSONALIZED MEDICINE

As a physician, I love the concepts put forth in Stephen S. Hall's "Personalized Medicine's Bitter Pill" (*TR* February 2003). However, there are other ways to improve the quality of care. Better decision-support tools would go a long way toward helping doctors distinguish differences among patients—differences that might otherwise elude the treating physician. Neural network computer systems, with their ability to recognize complex patterns, could tell us which patients will and will not respond to a particular treatment regimen. Drug and device companies can use neural networks to determine, from clinical-trial databases, the profile of the patients most likely to benefit from their products. That is personalized medicine.

Scott G. Tromanhauser, MD
Boston, MA

Two points in Hall's provocative article merit reexamination. First, the piece

focuses on the possibility that the total amount of genetic information we are born with will allow us to predict the utility of certain medications. The cancer treatment cited in the article, however, does not involve study of the genes we inherit. Instead, it depends on genes specific to tumors. The second point is that it may take enormous amounts of data to make accurate predictions on the basis of genetic predispositions. This could take a very long time.

Sigmund Weitzman, MD
Chicago, IL

EVOLUTION 2.0

The technology discussed in your interview with Gregory Stock about designer babies ("Point of Impact: Choosing Our Children's Genetic Futures," *TR* February 2003) is the sort of thing that makes people afraid of becoming obsolete. I can't help but think of books like *Brave New World* and *1984* and movies like *Gattaca,* which depict future civilizations where some humans are designated as superior to others. Because the human species has effectively negated the force of natural selection by managing to keep nearly all of its members alive until after procreation, it seems that it's time for another force to take its place. Why not call it synthetic selection?

Jeff Hull
Atlanta, GA

FREE-SOFTWARE IMPERATIVE

Simson Garfinkel did an excellent job of describing the potential threats to life and liberty faced by human rights workers who rely on proprietary software ("The Free-Software Imperative," *TR* February 2003). Many people in industrial countries who work in human rights are self-funded, or at best, are on severely limited budgets. The grass-roots nongovernmental organizations, by the very nature of their role and activities, operate at subsistence level. Thank you for giving exposure of this issue to an important audience.

Herbert F. Spirer
Stamford, CT

RED LIGHT, GREEN LIGHT

Researchers at Philips and the University of Amsterdam in the Netherlands have created the first material for light-emitting diodes (LEDs) and flat-panel displays that can glow two different colors. Other electroluminescent materials, like the familiar LED indicators on VCRs, emit light of one fixed hue when electricity flows through them. As a result, multicolor devices, such as flat-screen televisions and computer monitors, have required three different materials—one each for red, green, and blue.

A Philips researcher measures the optical properties of a two-color LED.

The new material is a mixture of a semiconducting polymer and a compound containing the metal ruthenium. Applying a voltage in one direction excites the metal, causing it to emit red light; an opposite voltage excites the polymer, which glows green. The dual-color material will allow designers to create full-color displays using two, rather than three, materials. This advance will simplify manufacture, and it will yield brighter displays because a larger portion of the screen surface will emit light at any given time. Philips expects the first small full-color displays that use the materials to be ready for market within three to five years.

A bicycle-powered computer brings the Internet to the village.

COMPUTERCYCLE

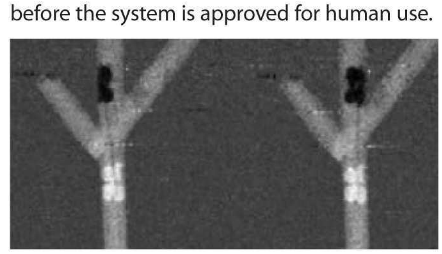
Villagers in remote parts of India will soon be surfing the Web, thanks to a new Internet-on-wheels device. Built by researchers at the Indian Institute of Technology in Kanpur, India, in collaboration with MIT's Media Lab Asia, Infothela consists of a covered tricycle with a steel platform that carries a computer linked to the Internet by a wireless antenna. A 12-volt battery tucked below the platform powers the computer: as the Infothela operator rides from village to village, offering Internet access at each stop, a pedal generator recharges the battery. Should the rider tire, the battery can be charged with electricity from an outlet or a diesel generator. The Indian researchers are working on ways to translate Internet content into local languages, and they are developing audio- and video-based software that would make the Net accessible to people who can't read. Prashant Kumar, head of the project's mechanical-design team, expects Infothela to begin its village-hopping voyage within the next three to five months.

COLOR CODER

Remember those red-and-green glasses that made some movies look 3-D? Now there's an easy way to create similar effects on any printed matter—without glasses. A new color-rendering process from Xerox Research and Technology in Webster, NY, prints two images on a single piece of paper in such a way that each image shows up only under specific lighting—red versus blue light, say. The heart of the system is new software that allows precise control over the process. The user tells the program which wavelengths of light should reveal each image, and it translates that into instructions for a standard printer. The technology could make document authentication that uses hidden watermarks cheap and simple, as well as allow for popcorn boxes that display different images depending on the light from a movie screen. Xerox has filed for patents on the technology.

REMOTE-CONTROL CATHETER

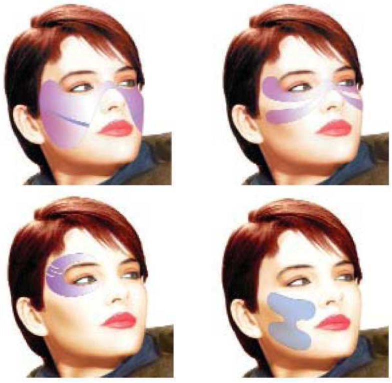
Doctors may soon be able to steer a catheter through blood vessels via remote control. Catheters—long, flexible tubes—are used for biopsies, drug delivery, and other crucial medical tasks. Manually maneuvering a catheter to its target requires a doctor to push and rotate the outside end while monitoring the progress via x-rays. The new navigation method, under development by radiologist Ronald Arenson at the University of California, San Francisco, uses magnetic technology. The catheter's tip is encircled by copper coils. As the patient lies within a magnetic field, a doctor uses a joystick to control the flow of electrical current to the coils; the current causes the catheter to realign itself with respect to the field. Such fine control, says Arenson, "will allow us to get to parts of the brain and body that are not easily accessible right now." Arenson says that it will be five to eight years before the system is approved for human use.



Electricity flowing to copper coils (black) helps steer a catheter through a branched channel.

COURTESY OF TIM ROBERTS, UNIVERSITY OF TORONTO (REMOTE-CONTROL CATHETER); COURTESY OF ABDUL QAVI (COMPUTERCYCLE); COURTESY OF PHILIPS RESEARCH (RED LIGHT, GREEN LIGHT)

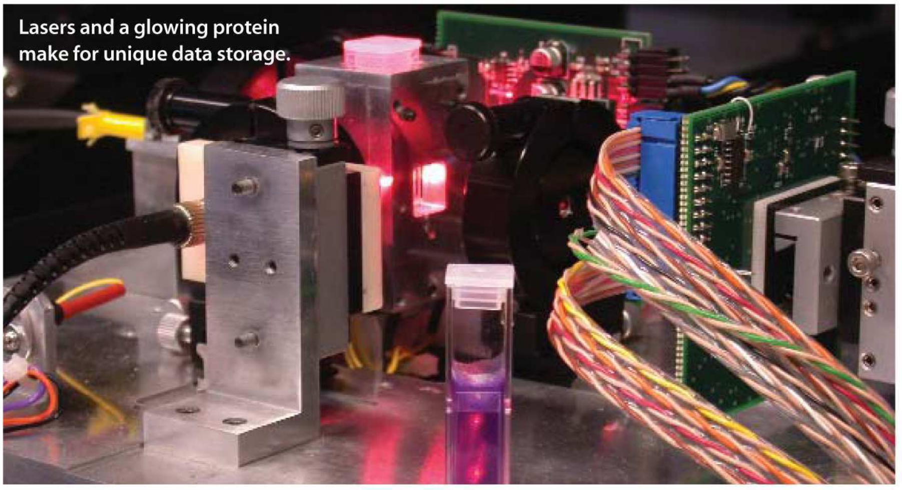
ELECTRIC BEAUTY



For years beauticians wielding handheld electrodes have used electricity to treat skin blemishes and to improve the absorption of creams and lotions. Now a thin disposable patch from PowerPaper in Einat, Israel, could let aesthetes do the same thing at home. The patch contains flexible, one-half-millimeter-thick 1.5-volt batteries that generate a weak current. The current travels to the skin via a printed electrode and an underlying layer of conductive gel. Used alone, say PowerPaper's developers, the system massages the skin and stimulates blood flow. Used in combination with, say, an antiwrinkle cream, the current drives positively charged molecules from the cream onto the skin—a process called iontophoresis, which, according to PowerPaper, speeds results of cosmetic treatments. The company is conducting tests with partners in the cosmetics industry and plans to market the patch by the end of this year.

SEWER SWEETENER

Environmental startup In-Pipe Technology has a cheap fix for today's overloaded sewage-treatment plants: a potent brew of bacteria that can digest society's effluent before it reaches the plant and can clean the sewer lines in the process. Bacteria are already critical sewage additives for treatment plants, but In-Pipe in Wheaton, IL, is the first to employ them under the streets. Released into sewer mains in a steady drip, In-Pipe's concentrated blend of naturally occurring bacteria colonizes the pipe walls, displacing indigenous microbes that emit offensive sulfurous odors and corrode the pipes. In-Pipe president Daniel Williamson says the colonizers are also efficient eaters, cutting by 50 to 85 percent the biosolids that make it to the plant. Most of In-Pipe's 14 installations are in southern states such as Florida, Mississippi, and Louisiana, where thanks to heat and humidity, sewer stench and corrosion are year-round nuisances. Armed with two years' worth of performance data, Williamson is raising funds to bring In-Pipe's relief to stinky sewers across the United States.



Lasers and a glowing protein make for unique data storage.

GLOWING MEMORY

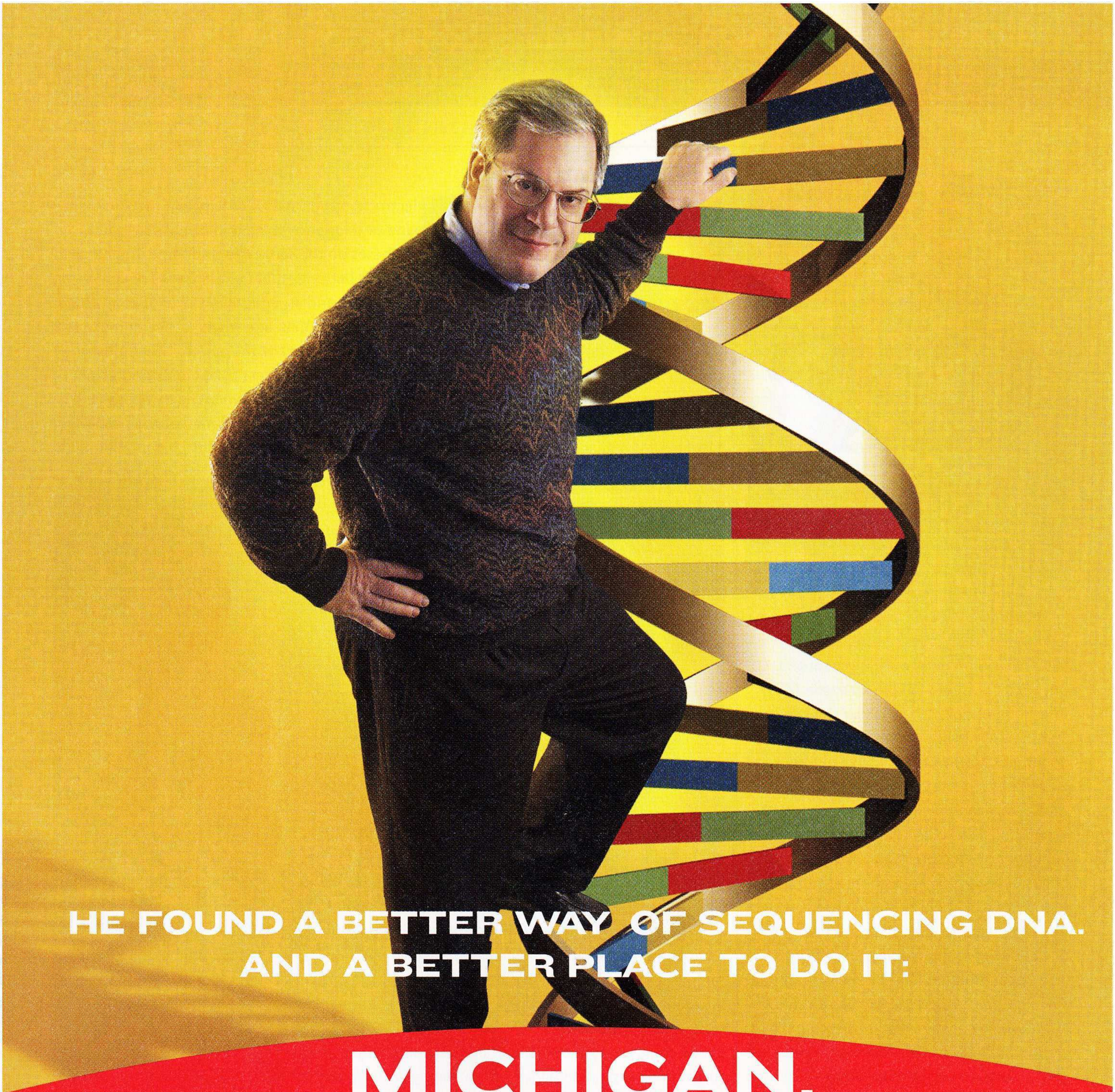
Because conventional computers work with one small chunk of data at a time, they're lousy at distinguishing faces and other subtly varying patterns. An "associative memory" under development at Syracuse University may solve the problem by enlisting a protein found in salt marsh bacteria. When exposed to laser light, the protein, called bacteriorhodopsin, twists into various positions that change its color. A database of images—faces, for instance—could be written by lasers into a layer of the protein. To find a match for an unidentified face, its image could be projected simultaneously onto all the images stored in the database; the superimposed pair of images whose features match most closely will glow the most brightly. A lab version of the system can already distinguish printed letters, but a commercial prototype is at least five years off, says Syracuse team leader Jeff Stuart. The researchers are looking for ways to write higher-resolution images with smaller lasers.

STRIKING LIGHTNING OUT

Lightning fries more than $1 billion worth of sensitive computer, television, and stereo equipment each year; startup Storm Shelter Electronics in Savannah, GA, has developed the first commercial device that provides protection from these massive power surges. Storm Shelter continuously monitors data from the National Lightning Detection Network (a network of sensors operated by Vaisala in Tucson, AZ) and wirelessly pages a user's device whenever lightning strikes within six kilometers. The device sounds an audible alert. Twenty seconds later, it disconnects the power to all linked electronics by creating an internal physical gap of two centimeters, across which an electrical surge as great as 34,000 volts cannot jump. (Standard surge protectors can handle spikes of only several hundred volts.) Once the threat has passed, Storm Shelter sends an all-clear page and reconnects the power. The company plans to start selling a commercial product in late spring; a consumer version is scheduled for next year.

A smarter surge protector.

COURTESY OF STORM SHELTER ELECTRONICS (STRIKING LIGHTNING); COURTESY OF JEFF STUART (GLOWING MEMORY); COURTESY OF POWERPAPER (ELECTRIC BEAUTY)



MICHIGAN.

Howard Cash created Sequencher which is the industry standard for DNA sequencing. His software is used worldwide to examine the mysteries of DNA. He started his company, Gene Codes Corporation, in Michigan's Life Sciences Corridor. Why? Because the talent pool and business climate are right. Michigan was recently ranked second in the nation for being the most business-friendly state.

And it might surprise you to learn that Michigan is one of the top 10 states for life sciences.

To find out more about what's going on in our Life Sciences Corridor and if your company should get in on it, call **1.800.946.6829** or visit **www.michigan.org**

www.michigan.org

MICHIGAN ECONOMIC DEVELOPMENT CORPORATION

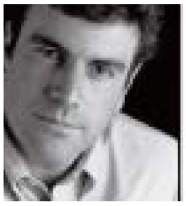
MICHIGAN | GREAT LAKES. GREAT LOCATION.

THE BEST SEGUE FOR SEGWAY

Dean Kamen's Segway is a superb technical achievement. Beautifully designed and intimately responsive, the high tech scooter puts the fun back into functional.

But Segway's marketplace success requires more than state-of-the-art engineering; it requires even more artful political lobbying. Why? Because Segways need sidewalks. A Segway without a sidewalk is like a BMW without an autobahn. Instead of being the Henry Ford or Alfred P. Sloan of sidewalks, Kamen could devolve into a pedestrian Preston Tucker—a visionary whose inventive prowess vastly exceeded his sales. Deregulating the sidewalks is the essential political innovation that will make Segways go.

Kamen has been enormously successful in persuading state legislatures to allow sidewalk access. So far, 33 states have approved sidewalk Segways with but a few restrictions such as requiring helmets for riders. In most states, bills were introduced to permit "electronic personal assistive mobility devices" on sidewalks. Given Kamen's impressive history as an inventor of technology for the physically challenged, many people interpreted that phrase to mean electric wheelchairs—nothing more. A terrific public-relations campaign conducted by Manchester, NH-based Segway, the company Kamen formed to market the scooter, combined with tightly controlled demonstrations of the vehicle in action, lubricated legislative acceptance nationwide.



It has been reported that the company spent less than $1 million on its lobbying efforts during the first year of the product launch. According to publicly filed records, Segway invested less than $100,000 lobbying for sidewalk access in California: a drop in the bucket compared to the $2.8 million Pacific Gas and Electric, the troubled power giant, spent over the same amount of time. The political payback arguably is worth more than the highest return on any of Segway's venture funding.

The legislative catch, however, is that in many states, jurisdiction over sidewalks belongs to the municipalities, some of which have proved skeptical of the novel vehicle. Fearing that Segways could become the equivalent of sidewalk sport-utility vehicles, San Francisco bureaucrats recently declined to grant permission that would let Kamen's machines mingle with the city's pedestrians. Several other communities have also expressed concern that Segways might be the wrong kind of revolution to bring to their crosswalks, plazas, and public spaces.

This worry is understandable. Automobile traffic is already a headache; what headaches might a slew of Segways bring to pedestrian traffic? The answer is far fuzzier than it should be. That's because Kamen's company has done a much better job prototyping the Segway than prototyping the Segway's potential sidewalk impact.

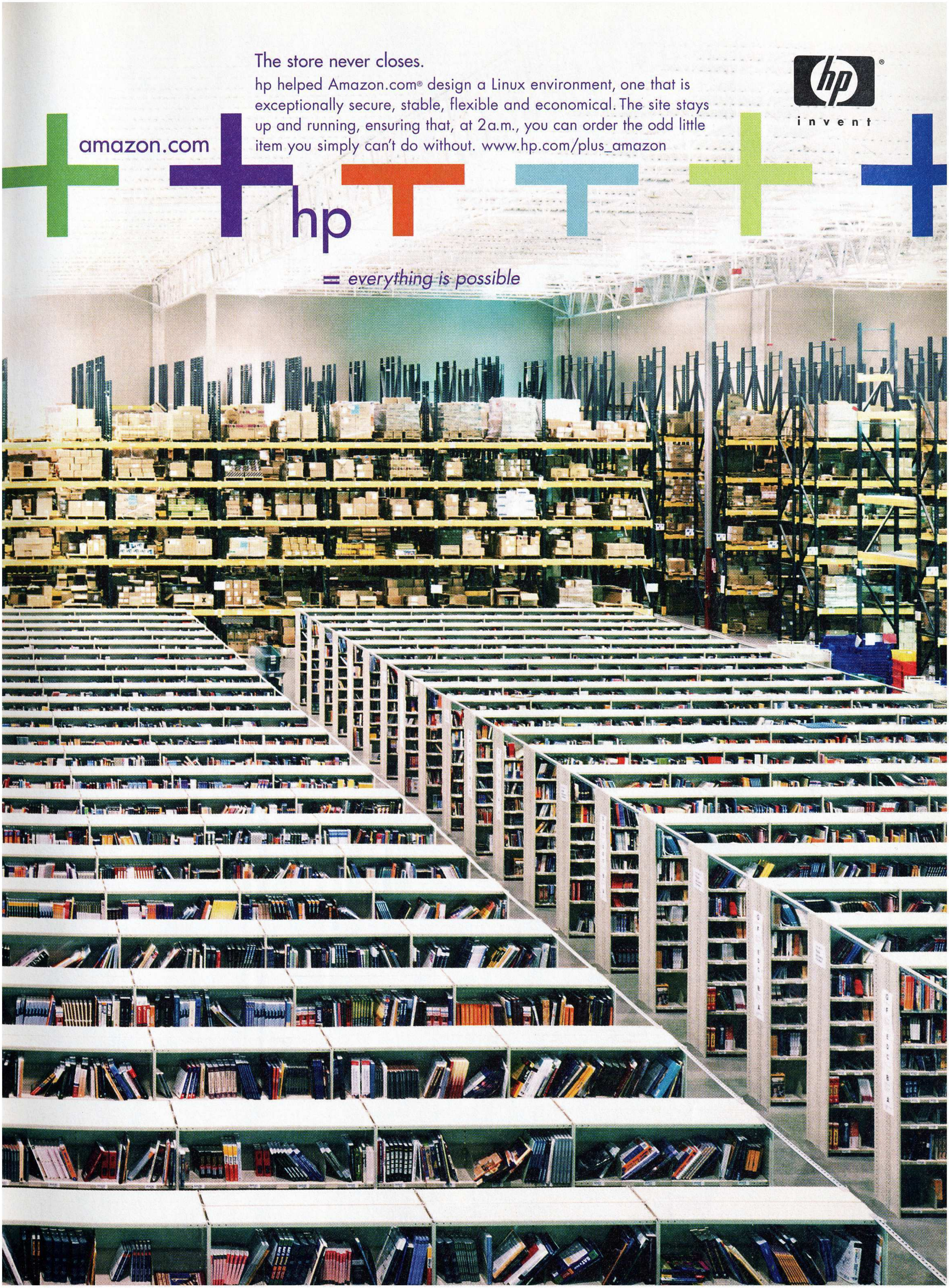
The company's lobbying efforts have been extraordinarily effective despite the paucity of its public- and pedestrian-impact research. But even superior lobbying goes only so far. In the hardball worlds of regulation, legislation, and litigation, the Segway cannot succeed unless it can be persuasively demonstrated that the vehicle's public benefits exceed its imposed costs.

If the Segway is to have any chance of becoming a mass transportation medium, the makers of the vehicle must model its impact as rigorously as they modeled the technology. They have to provide satisfactory answers to such questions as: What does a San Francisco sidewalk look like with five Segways vying for space? How quickly do Dallas pedestrians move when Segways are proceeding in rows rather than single file? When does the density of Segways in a crowded New York City intersection create a tipping point that turns pedestrian gridlock into midtown mayhem? Presenting such simulations to city planners and aldermen would help Segway's maker build credibility, trust, and insight into local circumstance.

If the Segway is to have any chance of becoming a widely used form of transportation, the makers of the vehicle must model its impact as rigorously as they modeled the technology.

Recognizing this analytical gap, Segway announced in January that it would use Celebration, FL, Disney's prefabricated city, as its most comprehensive test site for observing how well—or how poorly—Segways mix with the pedestrian masses. But that misses a terrific opportunity for innovators such as Kamen to simulate their inventions in the "real" world. Segway lends itself perfectly to computer modeling and simulation technologies that make public access easier to visualize and assess. It should be easy to simulate virtual Segways traveling the virtual sidewalks of San Francisco, Chicago, and Berlin. In the final analysis, giving legislators and the public tools that let them visualize and play with the possibilities posed by Segway-like innovations, Kamen could give the masses of potential customers the ultimate power to persuade themselves.

That's the real innovation challenge Kamen confronts. Most people are pretty happy with their cars; alas, most people are pretty unhappy about having to drive them in traffic. For the Segway to survive the next round of regulatory infighting, the company should rely on its virtual abilities to simulate the sidewalk rather than its physical capacity to take customers for a ride. TR

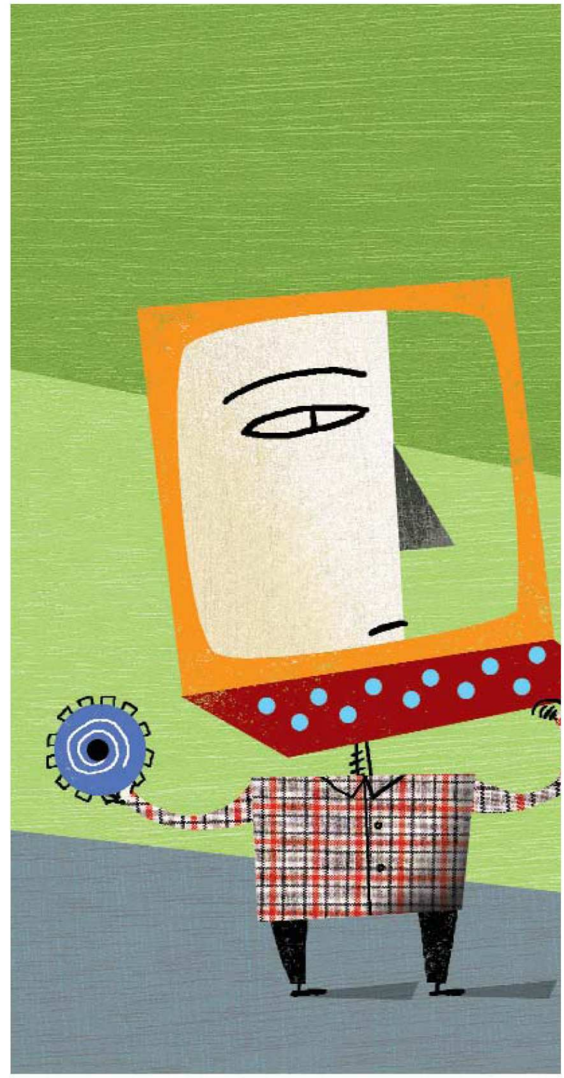

The store never closes.
hp helped Amazon.com® design a Linux environment, one that is exceptionally secure, stable, flexible and economical. The site stays up and running, ensuring that, at 2a.m., you can order the odd little item you simply can't do without. www.hp.com/plus_amazon
hp
invent
amazon.com
hp
= everything is possible


©2003 Hewlett-Packard Company. BirdLife Finland™ is a trademark of BirdLife Finland. Nowire™ is a trademark of Nowire Ltd.

hp
invent
Shh. The wily and elusive Great Snipe.
BirdLife Finland™ turned to hp and partner Nowire™ to develop the Bird Observation Service. Using GPS-equipped mobile phones, birdwatchers can instantly dispatch sightings with species and location information to a central database. This real-time information is a valuable conservation tool and indispensable to those curious as to why the Great Snipe isn't just So-So. www.hp.com/plus_birding
birdlife finland + hp
= everything is possible

WRITING SOFTWARE RIGHT

Companies invest in programs that banish bugs



Much of today's software is built and updated in a slapdash process. Programmers give life to cool new features in quick-and-dirty code, throw the code at a computer to see whether the program runs, and excise the worst bugs, one by one, until the program works well enough to release.

Naturally, many errors evade this kind of testing, and those that remain can create both minor annoyances and such major inconveniences as late January's worldwide Internet slowdown, the work of a self-replicating "worm" called Slammer that exploited a programming flaw in Microsoft's SQL Server software.

That laissez-faire design philosophy is coming under fire. Sun Microsystems, Microsoft, and IBM are all plotting ways to revolutionize the practice of software engineering. Although their strategies differ, the efforts are all geared toward saving time, reducing development costs, sparing programmers the more mind-numbing aspects of software debugging, and—most important for consumers and business users—producing software that works well the first time it's released.

"Our challenge is to get our software to the point that people expect it to work instead of expecting it to fail," says Jim Larus, leader of a software quality project at Microsoft Research in Redmond, WA.

One of the most radical attempts at improving software is under way at Sun Microsystems Laboratories in Santa Clara, CA. Code-named Jackpot, the project aims to overhaul the software-writing tools that have been created by Sun and many other software companies over the past 20 years. Most of these desktop programs comprise an editor to write and manipulate computer code; a debugger to search for the most common types of programming errors; and a compiler to translate programmers' computer code into the ones and zeroes that machines can act upon. The problem is that although these tools are good at finding such errors as misplaced punctuation, they can't see larger structural problems that make code inefficient, says Michael Van De Vanter, who runs the Jackpot group at Sun Laboratories.

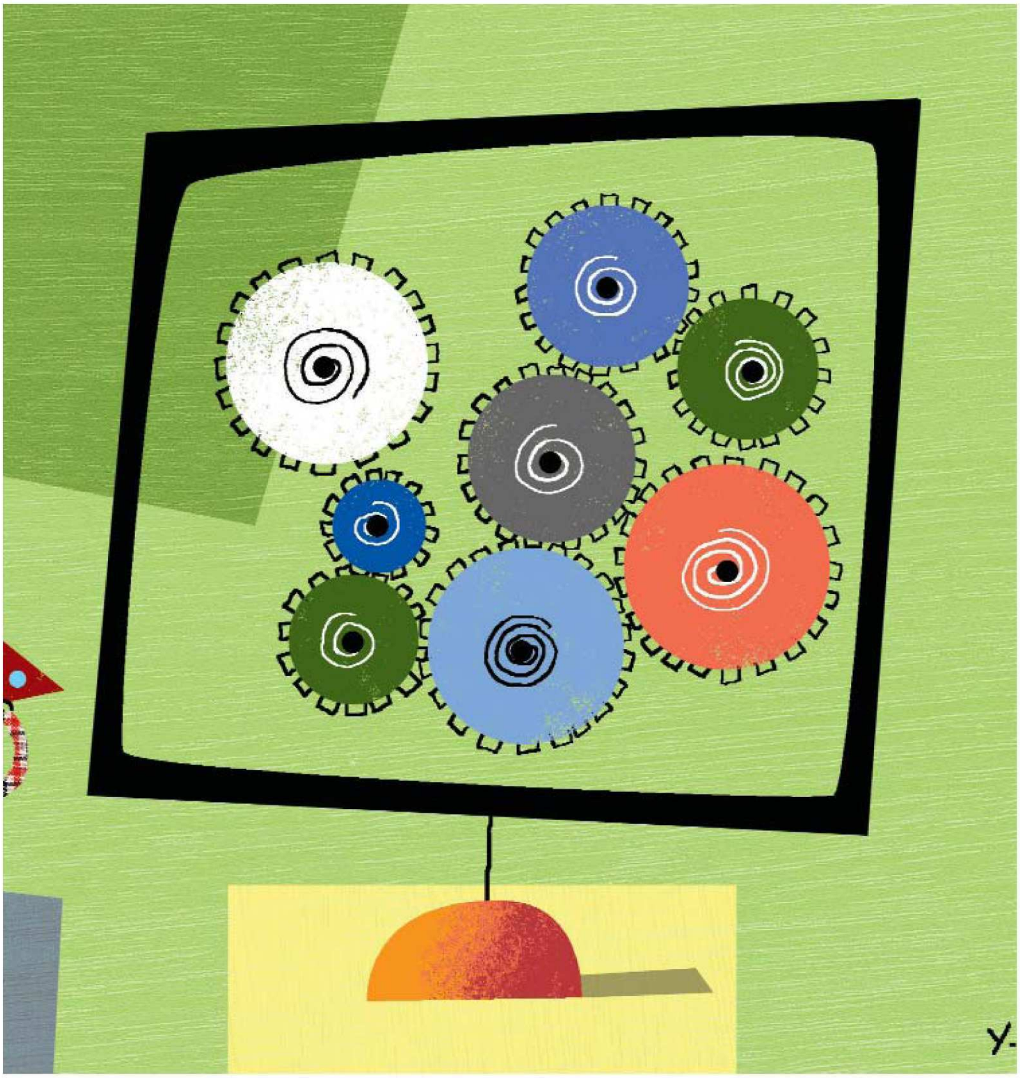
The solution: software that thinks about other software. Van De Vanter's team is building an "analysis engine" that reads a programmer's code and constructs an internal abstract model of the software. The group contends that such models will give programmers substantive real-time feedback as they work.

For example, the Jackpot team wants to provide programmers with a kind of meter that continually gauges a program's complexity—a step beyond the primitive measures, such as the number of lines in a program, provided by today's development tools. The analysis engine would detect whether complexity was getting out of hand—creating lots of hiding places for bugs—and would give programmers "an early warning," says Van De Vanter.

Helping programmers visualize their code is another way to battle complexity, he says. It's easy for software writers to nest instructions such as "if *x*, then *y*, else *z*" within other similar clauses—ad infinitum. But "there is a lot of psychological work showing that if they are nested too deep, people won't get it anymore," Van De Vanter says. The visual tools his team is developing would draw on the analysis engine to transform nested structures into easy-to-understand tables, maps, and highlighted text.

In addition, the Jackpot researchers are designing a debugger that doesn't simply find errors in programming syntax—a missing semicolon in a line of Java code, for example—but also identifies general instances of good or bad programming. "People tend to write code in predictable ways: the analogy in natural language is idiom," Van De Vanter explains. "We want something that will monitor for bad idioms." Widespread implementation of Jackpot at Sun is "several years out," he says, but the researchers plan to test it soon with Sun programmers.

While Sun is just beginning to explore advanced software-development tools, programmers at Microsoft have already come to depend on them. To get a handle on bugs in its Windows 2000 operating system, Microsoft paid more than $60 million in 1999 to acquire



JAMES YANG

Today's commercial software is so complex and unwieldy that its own programmers need help comprehending and debugging it. Where better to turn than—more software?

Intrinsa, maker of a bug-finding tool called Prefix. The program, which sifts through huge swaths of code searching for patterns that match a defined list of common semantic errors, helped find thousands of mistakes in Windows and other Microsoft products. But Prefix is slow and processor-intensive, requiring days of server time to analyze all of Windows. And because the bugs on its blacklist are "hard-wired," the program has to be rewritten before it can find new types of errors, says Microsoft's Larus.

To solve those problems, Microsoft is developing a new flexible version of the program. Like Sun's analysis engine, the Microsoft technology runs on programmers' desktops and transforms code into abstract structures that can be examined for trouble spots. But the program also allows the thousands of Microsoft programmers to create their own plug-ins that search for errors specific to the type of software being written. Although Microsoft is still refining its program, the company is already considering sharing the tool with companies that make programs for Windows.

And one step beyond these solutions is an experimental bug-finding tool called Slam, which is designed to catch every last deviation from a general programming rule. For instance, whenever programmers have put software "locks" on data to prevent interference while a certain section of their code is using the data, they should make sure to remove the locks before other sections of code take over. Slam can explore every conceivable path in a program's execution to make sure this happens. Slam is "complete," says Larus. "If it doesn't find this error, you know there aren't any."

Not all the ideas being pursued are technological. Some simply aim to get people together to solve problems. Two years ago IBM contributed $40 million to launch Eclipse, a nonprofit network of open-source software writers who are cooperating on the creation of a highly integrated development environment with built-in tools for creating software that runs on almost any operating system.

The essence of the project, says Eclipse board of directors chairman Skip McGaughey, is its democratic, open-source design process. "The general feeling," he says, "is that when the design stage is done in the open with many, many people participating, the odds of getting a design right are orders of magnitude better."

There's no way of knowing whether a more democratic engineering culture or the sophisticated debugging solutions now under investigation by software companies might have helped programmers catch the kind of oversight the Slammer worm exploited. But as code analysis technology itself grows more powerful, the payoff should be more reliable software for everyone. Says Microsoft's Larus, "I believe the only way we're going to get software to be acceptably better is to apply better tools to it." —*Wade Roush*

MAKING SPAM EXPENSIVE

Junk e-mailers shell out computing time

INTERNET | People love e-mail because it's easy and cheap. People hate spam—junk e-mail—well, because it's easy and cheap. At roughly a hundredth of a cent per message, a spammer can blast a million e-mails promoting ways to make money for a mere $100 initial investment. With such an economical advertising medium, it's hard for spammers *not* to recover their money. Unless, of course, they have to pay more for their trouble—a concept now being pursued at Microsoft.

Tools aimed at stemming the tide of electronic junk mail have proliferated recently, and most approaches rely on various filtering techniques. One common method is to search the subject line for certain words and such phrases as "eliminate debt" or "work from home." But those filters can also screen out legitimate e-mail that happens to contain the trigger words and can send critical e-mail unread to the "junk" folder, costing businesses dearly. That's why programmers have been looking for spam-blocking techniques that don't depend on message content.

Microsoft's concept is simple: make the sender's computer devote processor cycles to solving a mathematical problem. Incoming e-mail from an unknown sender gets delivered only once the recipient's computer verifies that a specific problem has been solved. "Computer time is money," says Cynthia Dwork, a Microsoft researcher who helped originate the idea while she was working at IBM. This cost won't overload legitimate mailers, who send only a few messages at a time, but it could be daunting for a spammer.

Over the last year, Joshua Goodman at Microsoft Research in Redmond, WA, has been working on ways to implement Dwork's idea. The challenge assigned by the recipient's computer, says Goodman, might be to solve a mathematical function that uses inputs such as the sender's name, recipient's name, time, and the content of the message itself as variables. Such an operation would typically take 10 seconds of computer time, says Dwork. That would limit a computer to sending some 8,000 e-mails a day—plenty for an individual but not enough to make it worth a spammer's while. For legitimate mass e-mail such as newsletters, subscribers could create rosters of known senders whose messages would be allowed through without their having to punch the computational ticket.

A similar project called Camram is under way in the open-source software community, says coordinator Eric S. Johansson. Goodman says, "We want to drive up the cost of using e-mail—not for the ordinary user but for the spammer." —*Herb Brody*

3-D MADE SIMPLE

IMAGING | **If the giant soda can that adorns your neighborhood vending machine looks so real you're ready to reach out and grab it, the image was probably created by an Israeli company that has invented a new way to produce stereo 3-D images from ordinary photographs.**

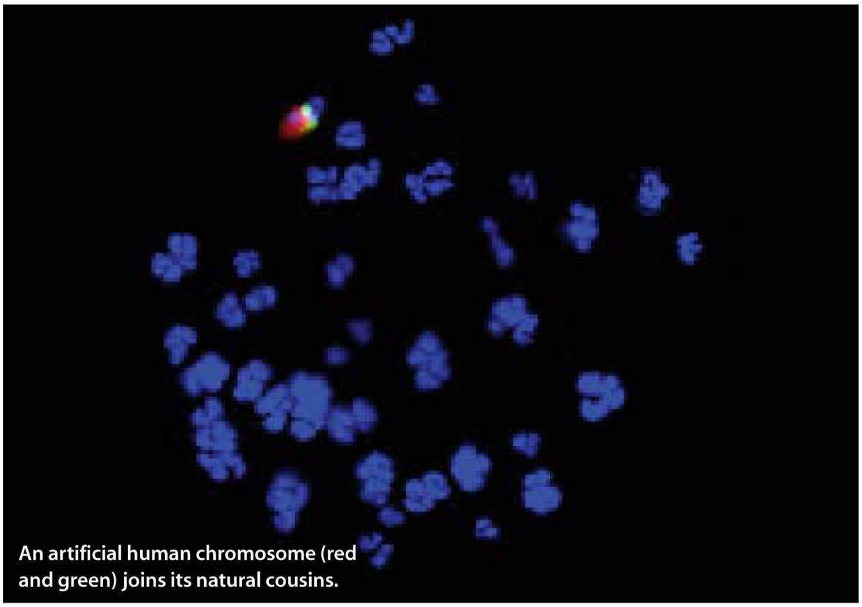
HumanEyes, based in Jerusalem, uses software algorithms developed by researchers at the Hebrew University of Jerusalem to analyze the images a digital camera records in continuous or video mode as it sweeps over a scene. The software examines and integrates dozens to hundreds of frames and creates a continuum of "virtual" views. One-pixel-wide slices of selected views are interlaced, and the processed image is printed and attached to lenticular plastic—sheets of long thin lenses.

These lenses send different underlying pictures to each eye, giving the viewer the illusion of depth. And as the viewer's angle shifts, different pairs of perspectives appear—just as if the viewer were walking past an actual scene. Other companies such as ProMagic in Vista, CA, also sell software for making lenticular images, but HumanEyes is the first to give stereoscopic photographs both realistic depth and this "panoramic" effect.

The technology's first outing is in Chile, where HumanEyes' images decorate Coca-Cola vending machines. Other companies will soon snap up the technology, predicts James Nail, a senior analyst with Forrester Research in Cambridge, MA. Meanwhile, HumanEyes is developing a home version of its software that will allow digital-camera hobbyists to create their own 3-D images. —*Tania Hershman*

As people move past a HumanEyes image, their view shifts just slightly from one perspective (left) to another (right).

COURTESY OF HUMANEYES (3-D); BRIAN STAUFFER (ILLUSTRATION)



An artificial human chromosome (red and green) joins its natural cousins.

CHROMOSOME CURE

BIOTECHNOLOGY | Every human cell carries 46 chromosomes, the DNA-and-protein packages that transmit genes from generation to generation as cells divide. Lately, scientists have been wondering whether they can fool the machinery of the cell by inserting a synthetic 47th chromosome furnished with genes of their own choosing. Two companies, Athersys in Cleveland, OH, and Chromos Molecular Systems in Burnaby, British Columbia, are beginning to find an answer; they are testing artificial chromosomes as a safe and effective way to introduce therapeutic genes into patients suffering from deadly genetic disorders.

Their hope is that the fake chromosomes will provide a viable alternative to conventional gene therapy, which typically uses viruses to deliver gene replacements in treatment of such diseases as hemophilia and cystic fibrosis. The small size of the viruses limits the number of genes that can be delivered, and because the viral proteins can also cause dangerous immune reactions, the strategy is risky. Artificial chromosomes might spare gene therapy patients from these problems. An artificial chromosome can carry any number of genes, is ignored by the immune system, and functions independently of other chromosomes, so the technique "represents potentially a response or an answer to those challenges," says Huntington F. Willard, director of the Duke University Institute for Genome Sciences and Policy. Willard and Athersys researchers created the first human artificial chromosomes five years ago.

Now Athersys and Chromos are trying to prove Willard right. In experiments on mice, Chromos has demonstrated that the bogus chromosomes are transmitted from mother cells to daughter cells during cell division and from one generation to the next as animals reproduce. More recently, Chromos scientists proved that they can raise red blood cell counts in mice by injecting cells that contain artificial chromosomes bearing the gene for erythropoeitin, a protein that stimulates blood cell production. If similar constructs work in humans, the company's potential targets include diabetes, hemophilia, and various metabolic disorders.

Willard anticipates that human trials are a year or more in the future. But skeptics abound. Michèle Calos, a Stanford University geneticist who previously had worked with artificial chromosomes, has since shifted her focus to other gene-therapy methods such as inserting therapeutic genes at specific places on natural chromosomes. Says Calos, "I'm not sure that that approach will make it to the clinic, because I think there might be alternatives that are just more competitive." —*Erika Jonietz*

INFINITE MESSAGING

BUSINESS | **Instant two-way text messaging, that ubiquitous medium of Web-surfing and cell-phone-toting teens, isn't just for socializing anymore. Because of the medium's immediacy—it's faster than e-mail but less intrusive than a phone call—"people are increasingly getting hooked on the need for continuous two-way text messaging as a coordination, alerting, and notification mechanism" for conducting business, says James Kobielus, a senior analyst with Burton Group, an e-business analysis firm in Alexandria, VA.**

In one sign of things to come, new software from MIR3 of San Diego, CA, ties a business's critical hardware or software into its instant-messaging network. If a Web server crashes or an inventory database shows that supplies are running low, the system can issue text or voice alerts to the proper employees.

To do this, MIR3 invented a "middleware" system that authenticates incoming notices from an organization's application software, determines who should receive them, and schedules delivery via media the recipients have chosen—from pagers to personal digital assistants. MIR3's early customers include hospitals, which use the technology to automatically alert nurses whenever, for instance, their patients' heart monitors register significant changes.

America Online, Microsoft, and Yahoo! have all announced plans to release secure corporate versions of their own popular messaging programs, and companies such as Beverly, MA-based Groove Networks are weaving instant messaging into online "collaboration environments" that could free employees from their physical offices. And that's something even adults can appreciate. —*Wade Roush*

JAMES YANG (ILLUSTRATION); COURTESY OF CHROMOS MOLECULAR SYSTEMS (CHROMOSOME)

The planned Fashion Show video wall.

THE WEB GOES BIG

DISPLAYS | Stadium Jumbotrons can show crude animations or a single live video image, and electronic signs such as the Reuters billboard in New York City's Times Square already post live Internet news feeds. But thanks to advances in software, huge new screens will soon weave together Web pages, Flash and Shockwave animation, and multiple video feeds of events taking place anywhere in the world.

Such gigantic displays are, in essence, the world's largest Internet terminals. To run the 365-square-meter video wall under construction at the Fashion Show shopping center in Las Vegas, NV, therefore, engineers at R/GA, a digital studio in New York, spent nine months building a powerful new "scheduling engine" based on extensible markup language, the emerging lingua franca of the Internet. The engine handles all the disparate types of media for the wall, and unlike the software that supported the first generation of large video displays and required powerful graphics supercomputers, it runs on a cluster of off-the-shelf PCs.

The display's ever-changing montage might show a live video feed of fashion models in Milan swooping across a background of still photos, getting bigger and then shrinking to nothing as the background dissolves to a commercial for jeans. "This level of control is very new," says John Mayo-Smith, R/GA's vice president of technology. And because they're connected to the Internet, he says, "these displays can be modified from anywhere and in real time." Talk about mass media. —*Susan Kuchinskas*

COMPUTING ON GLASS

A new form of silicon enables see-through circuitry

MATERIALS | Silicon is a substance that demands compromises. If you want fast electronics for your PC, you need the good stuff: single-crystal silicon. If you can do with somewhat slower electronics but need them to be thin and transparent for the screen of your laptop, you use slower amorphous silicon. A few years ago, attempting to achieve the best of both worlds, Sharp and Semiconductor Energy Laboratories in Japan collaborated to develop continuous-grain silicon, a new form of the element that's both transparent and relatively fast at carrying electrons. Now, applying the technology to assemble a rudimentary processor on the back of the pane of glass used for a liquid-crystal display (LCD), they have created a prototype "sheet computer."

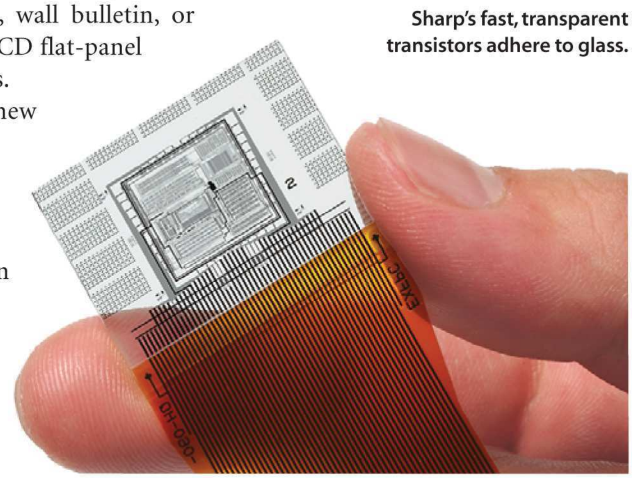
Continuous-grain silicon's slower cousin, amorphous silicon, can also be deposited in a see-through film onto glass and plastics. That makes it good for the thin-film transistors already used to control pixels in a laptop's active-matrix LCD; the material transports electrons fast enough to switch pixels on and off at the required 60 to 160 times per second. But the Sharp researchers found that continuous-grain silicon, composed of many small silicon crystals linked by atomic bonds, is a far more fluid medium for electrons: transistors made from the material can handle thousands or millions of switching operations per second—enough to run useful programs.

"Continuous-grain silicon…offers atomic-level continuity, which enables electrons to travel smoothly and with high mobility," explains Shigeo Misaka, the Sharp executive vice president in Japan who heads his company's research efforts.

In demonstrations in Japan last October, the 13,000-transistor prototype's clock speed hit 2.6 megahertz—not fast enough to run such programs as Microsoft Windows XP, which requires at least 233 megahertz of processor speed, but enough to manage such personal digital assistant (PDA) functions as datebooks, address books, and simple two-dimensional games. Because of continuous-grain silicon's 600-fold speed advantage over amorphous silicon, Sharp's prototype could be the precursor to a full-fledged sheet computer: a device with processor, memory, and LCD elements all bonded to a single layer of glass or plastic only a few millimeters thick. Such a computer need be no thicker than its screen. Within two years, Sharp expects to be using the technology to mass-produce fully functional PDAs the size and thickness of credit cards.

Continuous-grain silicon, however, offers only medium-speed-computing capabilities, says Philip J. Bos, a Kent State University physics professor who specializes in flat-panel, liquid-crystal media. "So you couldn't build a Pentium on this substrate, but it could likely serve as an electronic touch pad, wall bulletin, or PDA for the typical LCD flat-panel price of $200," he says.

Eventually, the new form of silicon could be used in products such as tablet computers, even flatter flat-screen monitors, and television screens thin enough to blend into walls. Not a bad compromise. —*Bruce Gain*



Sharp's fast, transparent transistors adhere to glass.

COURTESY OF SHARP (COMPUTING ON GLASS); COURTESY OF R/GA (WEB GOES BIG)

MIT technology insider

MIT Technology Insider is the only publication that follows the hundreds of innovative technologies conceived exclusively in the research labs and classrooms at MIT **AND** reports on patents issued, technologies licensed, and which companies are commercializing them.

MIT technology insider
FROM THE EDITORS OF TECHNOLOGY REVIEW

CONTENTS | 2.03

KEY

FUNDING
$ UNDER $2 MILLION
$$ $2 MIL.-$10 MIL.
$$$ $10 MILLION PLUS

PATENT STRENGTH
NO CORE PATENTS
CORE PROTECTION
DOMINANT POSITION

TIME TO MARKET
LESS THAN 1 YEAR
1-3 YEARS
MORE THAN 3 YEARS

AN MIT ENTERPRISE TECHNOLOGY

SPIN-OFF SPOTLIGHT

Reworking Wireless

EMBER CORPORATION IS DEVELOPING A NEW KIND OF NETWORK—ONE IT HOPES WILL UNWIRE INDUSTRIES WHILE CREATING NEW MARKETS.

Considering the murky climate of today's wire- less communications industry, Adrian Tuck's cheery take on the history of Ember Corporation may seem surprising. "I would love to give you a horror story, but I can't," laughs the executive vice president of the Boston-based company. Spun off from MIT's Media Lab nearly two years ago by cofounders Robert Poor and Andrew Wheeler, the company has raised $28 million in a downright dreary climate for finding venture capital and is actually shipping product to paying customers. Not too shabby for a startup market- ing a technology that many IT experts doubted would even work.

EMBER
$$$

Ember's technology is the hardware and software behind wireless sensor, or "mesh," networks. The systems consist of a series of small, low-powered nodes---circuit boards the size of a credit card---each contain- ing an eight-bit processor and a small antenna. Each node transmits a tiny amount of data---say the temperature reading of a water tank---to the nearest neighboring node, which then relays the message to the next node, and so on. The nodes quickly find the best route to bring the data to its destination: in this case, the thermostat that con- trols water temperature. Researchers at Ember want to create these self-configuring networks to carry out very simple, low-power tasks---like telling a light switch to dim or a heater to turn on---that don't require anything close to the signal strength of the Bluetooth or WiFi wireless systems used for larger data transmissions.

"Think streetlamps," says Poor, who received his PhD from the Media Lab in 2001. "Now, imagine if you put an Ember node in the ballast of every streetlamp in a city. First thing you can do is control the lamps more sensibly. You can find the ones that don't go on, and more important, the ones that are stuck on. Soon you have an entire city covered with this infrastructure."

And from there, says Poor, others would find reasons to keep adding to this network. For example, transportation companies could track bus schedules using nodes implanted on the buses themselves. As each bus passed a lamp, the node on the lamp could relay a message to the next bus stop, letting passengers know when the bus would arrive. Costs would be small because the backbone of the network would already have been laid out in the streetlamps. And that's just one off-the-cuff example. "We don't know what the killer app is yet," continues Poor, "but once the network starts growing, others will find more and more reason to join in."

While several major companies and labs---among them Motorola, Intel, and the Palo Alto Research Center---also are exploring self-configuring networks, Ember's founders believe their routing algorithm, patented by Poor in 2000, sets the Boston startup apart. The code enables each node to decide two things: whether or not to pass a given message along, and which particular node it should then pass the message to---never sending a message to more than one node at a time. This prevents the network from being overwhelmed with too much redundant data.

The evolution of Ember's nodes is displayed in the company lobby. Five versions are arranged chronologically, starting with Wheeler and Poor's 1999 Media Lab prototype that Poor tested by "networking" his home garden. This original

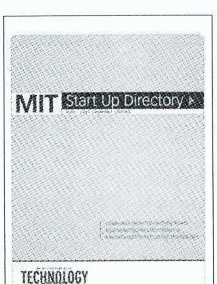
CONTINUED ON PAGE 2

UNDERWRITTEN BY
Hale and Dorr. When Success Matters.
Hale and Dorr LLP Counselors at Law <haledorr.com>

GET YOUR **FREE** SAMPLE ISSUE TODAY AT:

WWW.TECHNOLOGYINSIDER.COM/SAMPLE.ASP

Your PAID subscription includes:



The MIT Technology Insider

12 electronic issues at 24% off the regular price.

The MIT Startup Directory

A five-year compilation of almost 100 start-up companies that license MIT technologies.

The MIT Technology Insider Quarterly Report

A three-month wrap up of major research and development events connected with MIT research: what patents were secured, what companies were hatched, and what inventions were announced.

CLASS STRUGGLE

I am sitting in a classroom at Harvard Law School, and the professor is giving a fascinating lecture about the Federal Rules of Evidence and computer files. Nevertheless, I'm having a hard time keeping focused: my eyes keep wandering over to the fast-paced game of solitaire the student next to me is playing on her $3,000 laptop with its bright 15-inch screen. Other days, I've seen students watching feature-length DVDs—with subtitles turned on so they don't have to wear headphones.

Talk about misplaced priorities. Computers may have profoundly influenced the way universities operate, but the technology's presence has introduced new distractions and snafus. Many schools promote their wireless Internet connections to lure prospective students. Students take fuller sets of notes on their laptops than they ever could with pen and paper, but they continue to send e-mail to their friends even after the classes start. Professors seamlessly weave Internet content into their PowerPoint presentations, but their lectures fall flat when something goes wrong with the Internet connection.

Now that I'm in graduate school, I'm discovering that it's hard to make the claim that, on balance, all this fancy hardware is helping students learn better. Technology glitches frequently eat into class time: it's not uncommon for a lecture to start late because the professor can't get his laptop to work with the projector. One lecture I attended was delayed because the Internet connection was down, and the professor had neglected to save a copy of the course materials on his disk drive. Another class was interrupted when a pop-up ad appeared on the professor's screen, hawking "genuine college diplomas" for $99.95. (Who says irony is dead?) And it isn't just the science and engineering classes that are going high tech. Last fall, I took two classes at MIT's computer science department and two other courses at Harvard University. For the computer courses, both professors lectured with chalk in front of a blackboard; it was at *Harvard* that the professors used PCs.

I'm not arguing that schools and universities have erred in their adoption of information technology. But institutions of higher learning need to do a better job evaluating the ways students and faculty use the technology.

Consider MIT's Project Athena, a massive $70 million effort to integrate computers into undergraduate education. Athena got its start 20 years ago this spring, just months before I entered MIT as a wide-eyed freshman. Back then MIT was a computationally poor environment: most students were still using typewriters. One of Athena's big selling points was that through the use of simulation, numerical analysis, and collaboration tools, it would transform learning. Within eight years, MIT had set up more than a dozen computer "clusters," so students never had to walk more than a few minutes to reach a high-power workstation. A campuswide network linked the Athena clusters, allowing students to sit at any machine and access their files and electronic messages. All this seems ordinary today. In the mid-1980s it was radically new.

We early users of Athena felt as if we belonged to a privileged elite. But that status was short lived because Athena affected the entire culture of MIT. It didn't take long before every course, living group, and student activity had some sort of online component. This pattern has been repeated at other universities and throughout our society.

Technology's advance has not been kind to the Athena model. With so many students carrying laptops, the clusters of workstations that still dot the MIT campus are an answer to a problem that no longer exists. What's needed instead are facilities where teams of three to five students can get together to work on projects. I've tried holding such confabs in an Athena cluster, and it's brutal: just getting three adjacent terminals can be a challenge, and it's almost impossible to have a discussion without annoying everybody else in the vicinity. In an encouraging development, MIT's Hayden Library just opened a 24-hour study center with two small conference rooms that have chalkboards and wireless access (and glass walls for security). This 21st century study hall is probably a prototype of others to follow.

Computers have influenced the way universities operate, but the technology's presence has introduced new distractions and snafus. The lesson: buying computers is just the start of a larger commitment.

Perhaps the most important point is that educators and students must not let their knowledge of the technology stagnate. You can't learn sophisticated software by osmosis—or even by repeated use. Even the kids who appear to acquire computer skills with effortless ease need formal instruction to master sophisticated applications. Graphics, presentations, and data management are the lifeblood of the information economy: universities, and even grade schools, need to teach their students how to use the advanced features of these applications. Groups of students working on the same document, for example, should know how to use revision control features. And faculty who have started down the path of computer-assisted pedagogy must be able to anticipate the inevitable glitches and mishaps. Professors should know, for example, to replicate Web sites on their laptops so they can survive a faulty Net connection in the lecture hall. The real lesson here is that buying computers and deploying networks are just the start of a much larger commitment.

Meanwhile, I'm wishing "Ms. Solitaire" good luck on that law school final exam: she's going to need it. TR

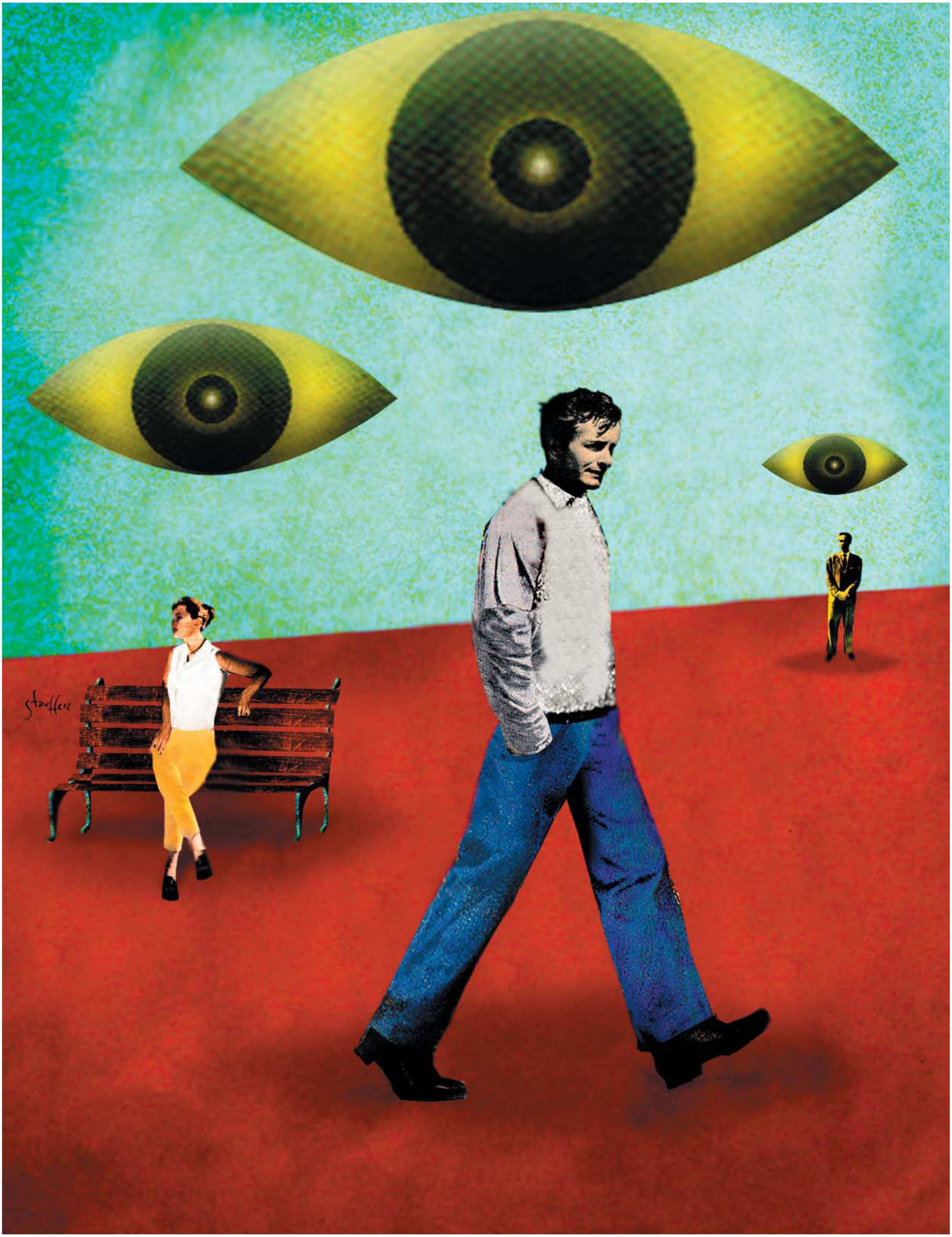
PART ONE

SURVEILLANCE NATION

Low-priced surveillance **technologies** will help **millions** of consumers protect their property, plan their commutes, and **monitor** their families. But as these informal intelligence-gathering networks overlap and invade our privacy, that very **security and convenience** could evaporate.

By Dan Farmer and Charles C. Mann

ILLUSTRATIONS BY BRIAN STAUFFER


stauffer

Route 9 is an old two-lane highway that cuts across Massachusetts from Boston in the east to Pittsfield in the west. Near the small city of Northampton, the highway crosses the wide Connecticut River. The Calvin Coolidge Memorial Bridge, named after the president who once served as Northampton's mayor, is a major regional traffic link. When the state began a long-delayed and still-ongoing reconstruction of the bridge in the summer of 2001, traffic jams stretched for kilometers into the bucolic New England countryside.

In a project aimed at alleviating drivers' frustration, the University of Massachusetts Transportation Center, located in nearby Amherst, installed eight shoe-size digital surveillance cameras along the roads leading to the bridge. Six are mounted on utility poles and the roofs of local businesses. Made by Axis Communications in Sweden, they are connected to dial-up modems and transmit images of the roadway before them to a Web page, which commuters can check for congestion before tackling the road. According to Dan Dulaski, the system's technical manager, running the entire webcam system—power, phone, and Internet fees—costs just $600 a month.

The other two cameras in the Coolidge Bridge project are a little less routine. Built by Computer Recognition Systems in Wokingham, England, with high-quality lenses and fast shutter speeds (1/10,000 second), they are designed to photograph every car and truck that passes by. Located eight kilometers apart, at the ends of the zone of maximum traffic congestion, the two cameras send vehicle images to attached computers, which use special character-recognition software to decipher vehicle license plates. The license data go to a server at the company's U.S. office in Cambridge, MA, about 130 kilometers away. As each license plate passes the second camera, the server ascertains the time difference between the two readings. The average of the travel durations of all successfully matched vehicles defines the likely travel time for crossing the bridge at any given moment, and that information is posted on the traffic watch Web page.

To local residents, the traffic data are helpful, even vital: police use the information to plan emergency routes. But as the computers calculate traffic flow, they are also making a record of all cars that cross the bridge—when they do so, their average speed, and (depending on lighting and weather conditions) how many people are in each car.

Trying to avoid provoking privacy fears, Keith Fallon, a Computer Recognition Systems project engineer, says, "we're not saving any of the information we capture. Everything is deleted immediately." But the company could change its mind and start saving the data at any time. No one on the road would know.

The Coolidge Bridge is just one of thousands of locations around the planet where citizens are crossing—willingly, more often than not—into a world of networked, highly computerized surveillance. According to a January report by J.P. Freeman, a security market-research firm in Newtown, CT, 26 million surveillance cameras have already been installed worldwide, and more than 11 million of them are in the United States. In heavily monitored London, England, Hull University criminologist Clive Norris has estimated, the average person is filmed by more than 300 cameras each *day*.

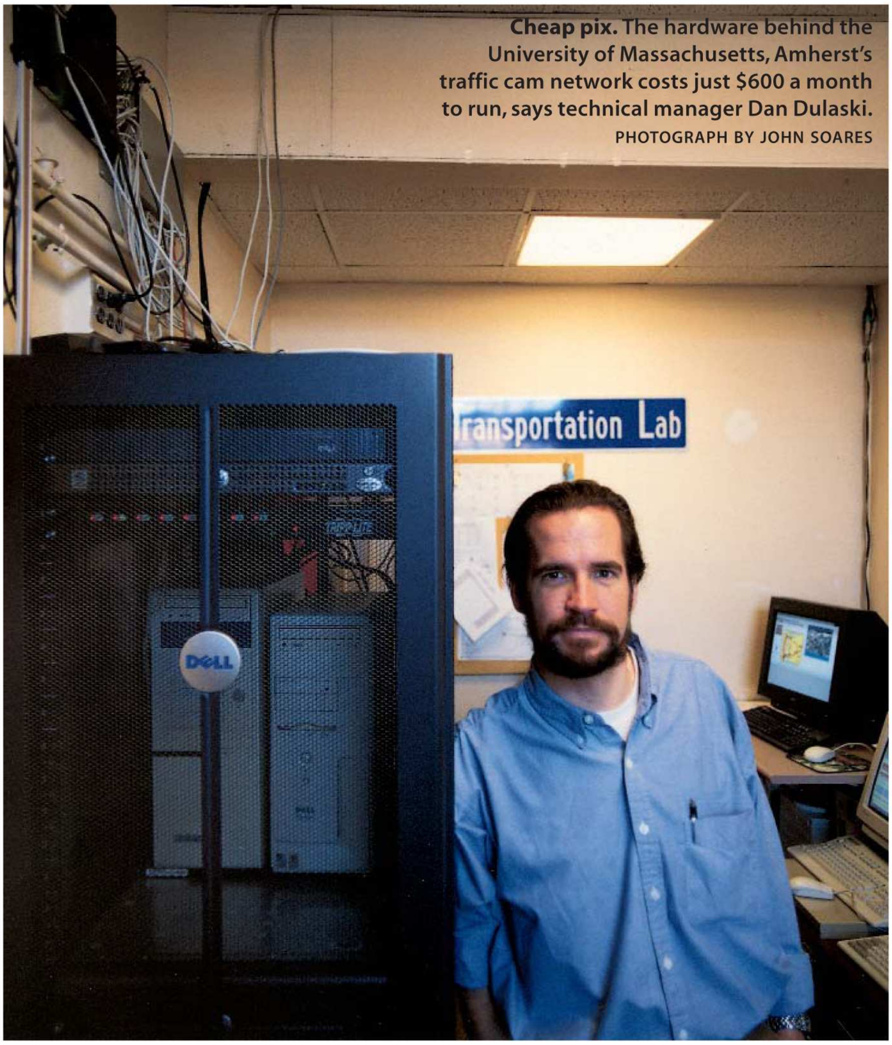
The $150 million-a-year remote digital-surveillance-camera market will grow, according to Freeman, at an annual clip of 40 to 50 percent for the next 10 years. But astonishingly, other, nonvideo forms of monitoring will increase even faster. In a process that mirrors the unplanned growth of the Internet itself, thousands of personal, commercial, medical, police, and government databases and monitoring systems will intersect and entwine. Ultimately, surveillance will become so ubiquitous, networked, and searchable that unmonitored public space will effectively cease to exist.

This prospect—what science fiction writer David Brin calls "the transparent society"—may sound too distant to be worth thinking about. But even the far-sighted Brin underestimated how quickly technological advances—more powerful microprocessors, faster network transmissions, larger hard drives, cheaper electronics, and more sophisticated and powerful software—would make universal surveillance possible.

It's not all about Big Brother or Big Business, either. Widespread electronic scrutiny is usually denounced as a creation of political tyranny or corporate greed. But the rise of omnipresent sur-

Road tools. Web-accessible video cameras installed near Northampton, MA, by the University of Massachusetts Transportation Center overlook the Calvin Coolidge Memorial Bridge on Route 9 (left). Two additional cameras photograph individual cars crossing the bridge (middle) and send the images to computers that isolate license plates and use machine vision algorithms to read the plate numbers (right). Once a plate has passed both cameras, the car's travel time is computed.

JOHN SOARES (CAMERAS); COURTESY OF DAN DULASKI (TRAFFIC IMAGES)



Cheap pix. The hardware behind the University of Massachusetts, Amherst's traffic cam network costs just $600 a month to run, says technical manager Dan Dulaski.
PHOTOGRAPH BY JOHN SOARES

veillance will be driven as much by ordinary citizens' understandable—even laudatory—desires for security, control, and comfort as by the imperatives of business and government. "Nanny cams," global-positioning locators, police and home security networks, traffic jam monitors, medical-device radio-frequency tags, small-business webcams: the list of monitoring devices employed by and for average Americans is already long, and it will only become longer. Extensive surveillance, in short, is coming into being because people like and want it.

"Almost all of the pieces for a surveillance society are already here," says Gene Spafford, director of Purdue University's Center for Education and Research in Information Assurance and Security. "It's just a matter of assembling them." Unfortunately, he says, ubiquitous surveillance faces intractable social and technological problems that could well reduce its usefulness or even make it dangerous. As a result, each type of monitoring may be beneficial in itself, at least for the people who put it in place, but the collective result could be calamitous.

To begin with, surveillance data from multiple sources are being combined into large databases. For example, businesses track employees' car, computer, and telephone use to evaluate their job performance; similarly, the U.S. Defense Department's experimental Total Information Awareness project has announced plans to sift through information about millions of people to find data that identify criminals and terrorists.

But many of these merged pools of data are less reliable than small-scale, localized monitoring efforts; big databases are harder to comb for bad entries, and their conclusions are far more difficult to verify. In addition, the inescapable nature of surveillance can itself create alarm, even among its beneficiaries. "Your little camera network may seem like a good idea to you," Spafford says. "Living with everyone else's could be a nightmare."

THE SURVEILLANCE AD-HOCRACY

Last October deadly snipers terrorized Washington, DC, and the surrounding suburbs, killing 10 people. For three long weeks, law enforcement agents seemed helpless to stop the murderers, who struck at random and then vanished into the area's snarl of highways. Ultimately, two alleged killers were arrested, but only because their taunting messages to the authorities had inadvertently provided clues to their identification.

In the not-too-distant future, according to advocates of policing technologies, such unstoppable rampages may become next to impossible, at least in populous areas. By combining police cameras with private camera networks like that on Route 9, video coverage will become so complete that any snipers who waged an attack—and all the people near the crime scene—would be trackable from camera to camera until they could be stopped and interrogated.

The unquestionable usefulness and sheer affordability of these extensive video-surveillance systems suggest that they will propagate rapidly. But despite the relentlessly increasing capabilities of such systems, video monitoring is still but a tiny part—less than 1 percent—of surveillance overall, says Carl Botan, a Purdue center researcher who has studied this technology for 15 years.

Examples are legion. By 2006, for instance, law will require that every U.S. cell phone be designed to report its precise location during a 911 call; wireless carriers plan to use the same technology to offer 24-hour location-based services, including tracking of people and vehicles. To prevent children from wittingly or unwittingly calling up porn sites, the Seattle company N2H2 provides Web filtering and monitoring services for 2,500 schools serving 16 million students. More than a third of all large corporations electronically review the computer files used by their employees, according to a recent American Management Association survey. Seven of the 10 biggest supermarket chains use discount cards to monitor customers' shopping habits: tailoring product offerings to customers' wishes is key to survival in that brutally competitive business. And as part of a new, federally mandated tracking system, the three major U.S. automobile manufacturers

plan to put special radio transponders known as radio frequency identification tags in every tire sold in the nation. Far exceeding congressional requirements, according to a leader of the Automotive Industry Action Group, an industry think tank, the tags can be read on vehicles going as fast as 160 kilometers per hour from a distance of 4.5 meters.

Many if not most of today's surveillance networks were set up by government and big business, but in years to come individuals and small organizations will set the pace of growth. Future sales of Net-enabled surveillance cameras, in the view of Fredrik Nilsson, Axis Communications' director of business development, will be driven by organizations that buy more than eight but fewer than 30 cameras—condo associations, church groups, convenience store owners, parent-teacher associations, and anyone else who might like to check what is happening in one place while he is sitting in another. A dozen companies already help working parents monitor their children's nannies and day-care centers from the office; scores more let them watch backyards, school buses, playgrounds, and their own living rooms. Two new startups—Wherify Wireless in Redwood Shores, CA, and Peace of Mind at Light Speed in Westport, CT—are introducing bracelets and other portable devices that continuously beam locating signals to satellites so that worried moms and dads can always find their children.

As thousands of ordinary people buy monitoring devices and services, the unplanned result will be an immense, overlapping grid of surveillance systems, created unintentionally by the same adhocracy that caused the Internet to explode. Meanwhile, the computer networks on which monitoring data are stored and manipulated continue to grow faster, cheaper, smarter, and able to store information in greater volume for longer times. Ubiquitous digital surveillance will marry widespread computational power—with startling results.

The factors driving the growth of computing potential are well known. Moore's law—which roughly equates to the doubling of processor speed every 18 months—seems likely to continue its famous march. Hard drive capacity is rising even faster. It has doubled every year for more than a decade, and this should go on "as far as the eye can see," according to

BY 2023 LARGE ORGANIZATIONS WILL BE ABLE TO DEVOTE THE EQUIVALENT OF A CONTEMPORARY PC TO MONITORING EVERY SINGLE ONE OF THE 330 MILLION PEOPLE WHO WILL BE LIVING IN THE UNITED STATES.

Robert M. Wise, director of product marketing for the desktop product group at Maxtor, a hard drive manufacturer. Similarly, according to a 2001 study by a pair of AT&T Labs researchers, network transmission capacity has more than doubled annually for the last dozen years, a tendency that should continue for at least another decade and will keep those powerful processors and hard drives well fed with fresh data.

Today a company or agency with a $10 million hardware budget can buy processing power equivalent to 2,000 workstations, two petabytes of hard drive space (two million gigabytes, or 50,000 standard 40-gigabyte hard drives like those found on today's PCs), and a two-gigabit Internet connection (more than 2,000 times the capacity of a typical home broadband connection). If current trends continue, simple arithmetic predicts that in 20 years the same purchasing power will buy the processing capability of 10 million of today's workstations, 200 exabytes (200 million gigabytes) of storage capacity, and 200 exabits (200 million megabits) of bandwidth. Another way of saying this is that by 2023 large organizations will be able to devote the equivalent of a contemporary PC to monitoring every single one of the 330 million people who will then be living in the United States.

One of the first applications for this combination of surveillance and computational power, says Raghu Ramakrishnan, a database researcher at the University of Wisconsin-Madison, will be continuous intensive monitoring of buildings, offices, and stores: the spaces where middle-class people spend most of their lives. Surveillance in the workplace is common now: in 2001, according to the American Management Association survey, 77.7 percent of major U.S. corporations electronically monitored their employees, and that statistic had more than doubled since 1997 *(see "Eye on Employees," p. 39)*. But much more is on the way. Companies like Johnson Controls and Siemens, Ramakrishnan says, are already "doing simplistic kinds of 'asset tracking,' as they call it." They use radio frequency identification tags to monitor the locations of people as well as inventory. In January, Gillette began attaching such tags to 500 million of its Mach 3 Turbo razors. Special "smart shelves" at Wal-Mart stores will record the removal of razors by shoppers, thereby alerting stock clerks whenever shelves need to be refilled—and

effectively transforming Gillette customers into walking radio beacons. In the future, such tags will be used by hospitals to ensure that patients and staff maintain quarantines, by law offices to keep visitors from straying into rooms containing clients' confidential papers, and in kindergartens to track toddlers.

By employing multiple, overlapping types of monitoring, Ramakrishnan says, managers will be able to "keep track of people, objects, and environmental levels throughout a whole complex." Initially, these networks will be installed for "such mundane things as trying to figure out when to replace the carpets or which areas of lawn get the most traffic so you need to spread some grass seed preventively." But as computers and monitoring equipment become cheaper and more powerful, managers will use surveillance data to construct complex, multidimensional records of how spaces are used. The models will be analyzed to improve efficiency and security—and they will be sold to other businesses or governments. Over time, the thousands of individual monitoring schemes inevitably will merge together and feed their data into large commercial and state-owned networks. When surveillance databases can describe or depict what every individual is doing at a particular time, Ramakrishnan says, they will be providing humankind with the digital equivalent of an ancient dream: being "present, in effect, almost anywhere and anytime."

GARBAGE IN, GRAGBEA OTU

In 1974 Francis Ford Coppola wrote and directed *The Conversation*, which starred Gene Hackman as Harry Caul, a socially maladroit surveillance expert. In this remarkably prescient movie, a mysterious organization hires Caul to record a quiet discussion that will take place in the middle of a crowd in San Francisco's Union Square. Caul deploys three microphones: one in a bag carried by a confederate and two directional mikes installed on buildings overlooking the area. Afterward Caul discovers that each of the three recordings is plagued by background noise and distortions, but by combining the different sources, he is able to piece together the conversation. Or, rather, he thinks he has pieced it together. Later, to his horror, Caul learns that he misinterpreted a crucial line, a discovery that leads directly to the movie's chilling denouement.

The Conversation illustrates a central dilemma for tomorrow's surveillance society. Although much of the explosive growth in monitoring is being driven by consumer demand, that growth has not yet been accompanied by solutions to the classic difficulties computer systems have integrating disparate sources of information and arriving at valid conclusions. Data quality problems that cause little inconvenience on a local scale—when Wal-Mart's smart shelves misread a razor's radio frequency identification tag—have much larger consequences when organizations assemble big databases from many sources and attempt to draw conclusions about, say, someone's capacity for criminal action. Such problems, in the long run, will play a large role in determining both the technical and social impact of surveillance.

The experimental and controversial Total Information Awareness program of the Defense Advanced Research Projects Agency exemplifies these issues. By merging records from corporate, medical, retail, educational, travel, telephone, and even veterinary sources, as well as such "biometric" data as fingerprints, iris and retina scans, DNA tests, and facial-characteristic measurements, the program is intended to create an unprecedented repository of information about both U.S. citizens and foreigners with U.S. contacts. Program director John M. Poindexter has explained that analysts will use custom data-mining techniques to sift through the mass of information, attempting to "detect, classify, and identify foreign terrorists" in order to "preempt and defeat terrorist acts"—a virtual Eye of Sauron, in critics' view, constructed from telephone bills and shopping preference cards.

In February Congress required the Pentagon to obtain its specific approval before implementing Total Information Awareness in the United States (though certain actions are allowed on foreign soil). But President George W. Bush had already announced that he was creating an apparently similar effort, the Terrorist Threat Integration Center, to be led by the Central Intelligence Agency. Regardless of the fate of these two programs, other equally sweeping attempts to pool monitoring data are proceeding apace. Among these initiatives is Regulatory DataCorp, a for-profit consortium of 19 top financial institutions worldwide. The consortium, which was formed last July, combines members' customer data in an effort to combat "money laundering, fraud, terrorist financing, organized crime, and corruption." By constantly poring through more than 20,000 sources of public information about potential wrongdoings—from newspaper articles and Interpol warrants to disciplinary actions by the U.S. Securities and Exchange Commission—the consortium's Global Regulatory Information Database will, according to its owner, help clients "know their customers."

Eye on Employees

Percentage of major U.S. employers that record and review their workers' activities

SURVEILLANCE ACTIVITY	1997	1998	1999	2000	2001
Recording telephone conversations	10.4	11.2	10.6	11.5	11.9
Monitoring telephone usage	34.4	40.2	38.6	44.0	43.3
Storing and reviewing voice mail	5.3	5.3	5.8	6.8	7.8
Storing and reviewing computer files	13.7	19.6	21.4	30.8	36.1
Storing and reviewing e-mail	14.9	20.2	27.0	38.1	46.5
Monitoring Internet connections	NA[1]	NA[1]	NA[1]	54.1	62.8
Clocking overall computer use	16.1	15.9	15.2	19.4	18.9
Video recording of employee performance	15.7	15.6	16.1	14.6	15.2
Video surveillance for security	33.7	32.7	32.8	35.3	37.7
Any active electronic monitoring	35.3	42.7	45.1	73.5[2]	77.7[2]

1. NOT AVAILABLE. 2. INCLUDES INTERNET MONITORING, WHICH WAS NOT MEASURED PRIOR TO 2000.

SOURCE: AMERICAN MANAGEMENT ASSOCIATION

Equally important in the long run are the databases that will be created by the nearly spontaneous aggregation of scores or hundreds of smaller databases. "What seem to be small-scale, discrete systems end up being combined into large databases," says Marc Rotenberg, executive director of the Electronic Privacy Information Center, a nonprofit research organization in Washington, DC. He points to the recent, voluntary efforts of merchants in Washington's affluent Georgetown district. They are integrating their in-store closed-circuit television networks and making the combined results available to city police. In Rotenberg's view, the collection and consolidation of individual surveillance networks into big government and industry programs "is a strange mix of public and private, and it's not something that the legal system has encountered much before."

Managing the sheer size of these aggregate surveillance databases, surprisingly, will not pose insurmountable technical difficulties. Most personal data are either very compact or easily compressible. Financial, medical, and shopping records can be represented as strings of text that are easily stored and transmitted; as a general rule, the records do not grow substantially over time.

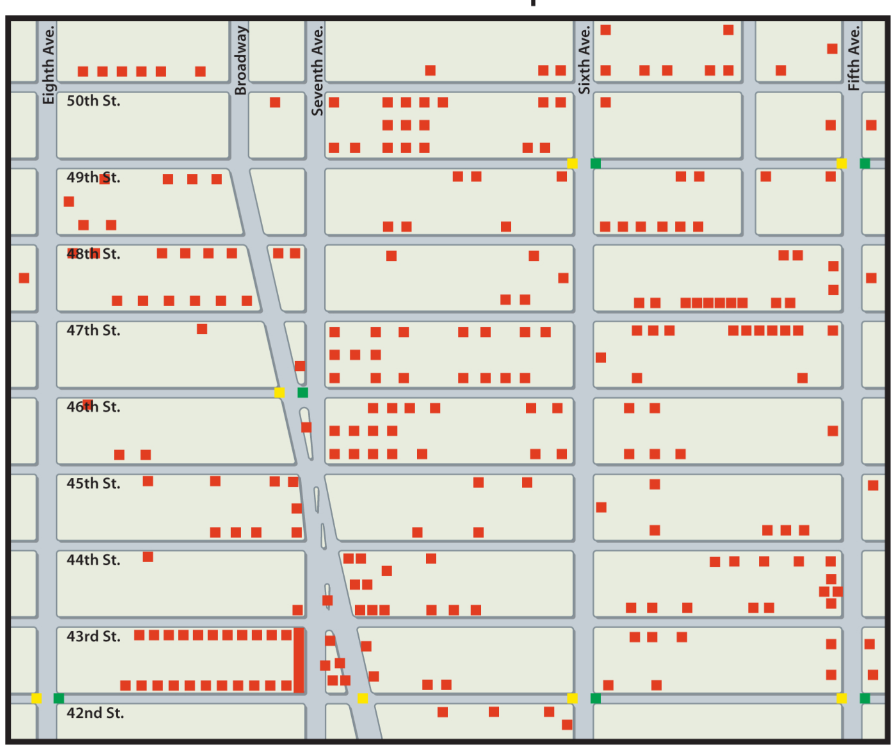
Even biometric records are no strain on computing systems. To identify people, genetic-testing firms typically need stretches of DNA that can be represented in just one kilobyte—the size of a short e-mail message. Fingerprints, iris scans, and other types of biometric data consume little more. Other forms of data can be preprocessed in much the way that the cameras on Route 9 transform multimegabyte images of cars into short strings of text with license plate numbers and times. (For investigators, having a video of suspects driving down a road usually is not as important as simply knowing that they were there at a given time.) To create a digital dossier for every individual in the United States—as programs like Total Information Awareness would require—only "a couple terabytes of well-defined information" would be needed, says Jeffrey Ullman, a former Stanford University database researcher. "I don't think that's really stressing the capacity of [even today's] databases."

Instead, argues Rajeev Motwani, another member of Stanford's database group, the real challenge for large surveillance databases will be the seemingly simple task of gathering valid data. Computer scientists use the term GIGO—garbage in, garbage out—to describe situations in which erroneous input creates erroneous output. Whether people are building bombs or buying bagels, governments and corporations try to predict their behavior by integrating data from sources as disparate as electronic toll-collection sensors, library records, restaurant credit-card receipts, and grocery store customer cards—to say nothing of the Internet, surely the world's largest repository of personal information. Unfortunately, all these sources are full of errors, as are financial and medical records. Names are misspelled and digits transposed; address and e-mail records become outdated when people move and switch Internet service providers; and formatting differences among databases cause information loss and distortion when they are merged. "It is routine to find in large customer databases defective records—records with at least one major error or omission—at rates of at least 20 to 35 percent," says Larry English of Information Impact, a database consulting company in Brentwood, TN.

Unfortunately, says Motwani, "data cleaning is a major open problem in the research community. We are still struggling to get a formal technical definition of the problem." Even when the original data are correct, he argues, merging them can introduce errors where none had existed before. Worse, none of these worries about the garbage going into the system even begin to address the still larger problems with the garbage going out.

ALREADY, 26 MILLION SURVEILLANCE CAMERAS HAVE BEEN INSTALLED WORLDWIDE, AND 11 MILLION OF THEM ARE IN THE UNITED STATES. MORE AND MORE, THE DATA FROM THESE CAMERAS ARE BEING POOLED.

Cameras Canvass Times Square



People passing through Manhattan's Times Square area leave a trail of images on scores of webcams and private and city-owned surveillance cameras. New York privacy activist Bill Brown compiled this map in September 2002.

- METROCOMMUTE TRAFFIC CAMS
- NEW YORK CITY DEPARTMENT OF TRANSPORTATION TRAFFIC CAMS
- ALL OTHER CAMERAS

JOHN MACNEILL; SOURCES: BILL BROWN/SURVEILLANCE CAMERA PLAYERS; METROCOMMUTE; NEW YORK CITY DEPARTMENT OF TRANSPORTATION


File Actions Tools Communicate Status Reports
WHERE ON EARTH ARE THEY DEVELOPING VIRTUAL EMERGENCIES THAT WILL IMPROVE HOW FIRST RESPONDERS DEAL WITH REAL ONES?
10:50:54


stauffer

THE DISSOLUTION OF PRIVACY

Almost every computer-science student takes a course in algorithms. Algorithms are sets of specified, repeatable rules or procedures for accomplishing tasks such as sorting numbers; they are, so to speak, the engines that make programs run. Unfortunately, innovations in algorithms are not subject to Moore's law, and progress in the field is notoriously sporadic. "There are certain areas in algorithms we basically can't do better and others where creative work will have to be done," Ullman says. Sifting through large surveillance databases for information, he says, will essentially be "a problem in research in algorithms. We need to exploit some of the stuff that's been done in the data-mining community recently and do it much, much better."

Working with databases requires users to have two mental models. One is a model of the data. Teasing out answers to questions from the popular search engine Google, for example, is easier if users grasp the varieties and types of data on the Internet—Web pages with words and pictures, whole documents in a multiplicity of formats, downloadable software and media files—and how they are stored. In exactly the same way, extracting information from surveillance databases will depend on a user's knowledge of the system. "It's a chess game," Ullman says. "An unusually smart analyst will get things that a not-so-smart one will not."

Second, and more important according to Spafford, effective use of big surveillance databases will depend on having a model of what one is looking for. This factor is especially crucial, he says, when trying to predict the future, a goal of many commercial and government projects. For this reason, what might be called *reactive* searches that scan recorded data for specific patterns are generally much more likely to obtain useful answers than *proactive* searches that seek to get ahead of things. If, for instance, police in the Washington sniper investigation had been able to tap into a pervasive network of surveillance cameras, they could have tracked people seen near the crime scenes until they could be stopped and questioned: a reactive process. But it is unlikely that police would have been helped by proactively asking surveillance databases for the names of people in the Washington area with the requisite characteristics (family difficulties, perhaps, or military training and a recent penchant for drinking) to become snipers.

In many cases, invalid answers are harmless. If Victoria's Secret mistakenly mails 1 percent of its spring catalogs to people with no interest in lingerie, the price paid by all parties is small. But if a national terrorist-tracking system has the same 1 percent error rate, it will produce millions of false alarms, wasting huge amounts of investigators' time and, worse, labeling many innocent U.S. citizens as suspects. "A 99 percent hit rate is great for advertising," Spafford says, "but terrible for spotting terrorism."

IF A NATIONAL TERRORIST-TRACKING SYSTEM HAS EVEN A 1 PERCENT ERROR RATE, IT WILL PRODUCE MILLIONS OF FALSE ALARMS, WASTING TIME AND LABELING INNOCENT U.S. CITIZENS AS SUSPECTS.

Because no system can have a success rate of 100 percent, analysts can try to decrease the likelihood that surveillance databases will identify blameless people as possible terrorists. By making the criteria for flagging suspects more stringent, officials can raise the bar, and fewer ordinary citizens will be wrongly fingered. Inevitably, however, that will mean also that the "borderline" terrorists—those who don't match all the search criteria but still have lethal intentions—might be overlooked as well. For both types of error, the potential consequences are alarming.

Yet none of these concerns will stop the growth of surveillance, says Ben Shneiderman, a computer scientist at the University of Maryland. Its potential benefits are simply too large. An example is what Shneiderman, in his recent book *Leonardo's Laptop: Human Needs and the New Computing Technologies*, calls the World Wide Med: a global, unified database that makes every patient's complete medical history instantly available to doctors through the Internet, replacing today's scattered sheaves of paper records *(see "Paperless Medicine," p. 58)*. "The idea," he says, "is that if you're brought to an ER anywhere in the world, your medical records pop up in 30 seconds." Similar programs are already coming into existence. Backed by the Centers for Disease Control and Prevention, a team based at Harvard Medical School is planning to monitor the records of 20 million walk-in hospital patients throughout the United States for clusters of symptoms associated with bioterror agents. Given the huge number of lost or confused medical records, the benefits of such plans are clear. But because doctors would be continually adding information to medical histories, the system would be monitoring patients' most intimate personal data. The network, therefore, threatens to violate patient confidentiality on a global scale.

In Shneiderman's view, such trade-offs are inherent to surveillance. The collective by-product of thousands of unexceptionable, even praiseworthy efforts to gather data could be something nobody wants: the demise of privacy. "These networks are growing much faster than people realize," he says. "We need to pay attention to what we're doing right now."

In *The Conversation*, surveillance expert Harry Caul is forced to confront the trade-offs of his profession directly. The conversation in Union Square provides information that he uses to try to stop a murder. Unfortunately, his faulty interpretation of its meaning prevents him from averting tragedy. Worse still, we see in scene after scene that even the expert snoop is unable to avoid being monitored and recorded. At the movie's intense, almost wordless climax, Caul rips his home apart in a futile effort to find the electronic bugs that are hounding him.

The Conversation foreshadowed a view now taken by many experts: surveillance cannot be stopped. There is no possibility of "opting out." The question instead is how to use technology, policy, and shared societal values to guide the spread of surveillance—by the government, by corporations, and perhaps most of all by our own unwitting and enthusiastic participation—while limiting its downside. TR

Next month: how surveillance technology is changing our definition of privacy—and why the keys to preserving it may be in the technology itself.

Plain rocket: It's an early prototype, but the EZ-Rocket, built by Xcor Aerospace, is one of a new breed of privately developed reusable rocket planes that could generate revenue from tourism and satellite launches and drive advances in space technology.

COUNTDOWN FOR ROCKET PLANES

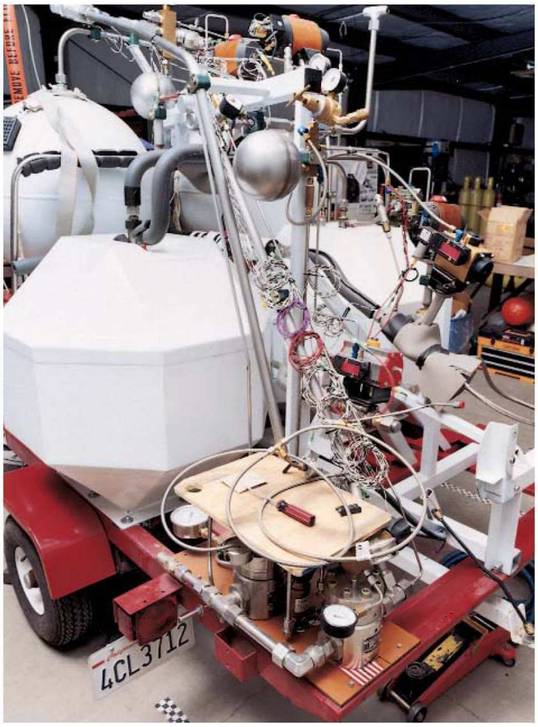
IN THE WAKE OF THE SPACE SHUTTLE COLUMBIA DISASTER, SCRAPPY PRIVATE COMPANIES TESTING ROCKET-POWERED CRAFT ON DESERT RUNWAYS MIGHT BE THE ONES PROVIDING THE NEXT GENERATION OF LAUNCH TECHNOLOGIES.

BY DAVID CHANDLER, PHOTOGRAPHS BY SIAN KENNEDY

THE SUN-BAKED TOWN OF MOJAVE, CA, WITH A POPULATION OF ONLY 3,700, boasts an airport that takes up almost as much area as Los Angeles International. The vast, isolated site at the mountain-rimmed edge of a wide expanse of high desert plain, has been home to several maverick aerospace companies. Voyager, the extremely lightweight airplane that in 1986 became the first to fly nonstop around the world without refueling, was spawned here. Now, in an unassuming low building at the airport's edge, the future of space transportation is, just possibly, being born.

Mind you, that future doesn't look like much yet: a tiny two-seat airplane that resembles a jet fighter with its tail chopped off and stubby winglets installed near its nose. Last July this lightweight craft, dubbed EZ-Rocket, reached a new aviation milestone when pilot Dick Rutan, who had also piloted Voyager, put its twin rocket motors through a pivotal "touch and go" maneuver: taking off, shutting down the engines, landing, firing up the motors again, and taking off without stopping. This represented a high-water mark in giving airplanelike flexibility and controllability to a rocket-powered craft: an achievement that carries heightened significance since the Space Shuttle Columbia catastrophe raised new questions about the viability of the U.S. government's manned space program.

Each of those two flights lasted less than 15 minutes and neither reached altitudes higher than 3,000 meters. But they showed that Xcor Aerospace, the company behind EZ-Rocket, may have the best shot yet at actually giving the world a reusable rocket plane—bringing routine airlinelike operations to the world of rocketry and slashing launch costs to as little as one-tenth those of launching the space shuttle and today's expendable rockets. Such a craft could, within several years, allow cheap satellite



Rocket checker: Xcor's EZ-Rocket engine test stand includes two octagonal oxygen tanks and two spherical fuel tanks on a trailer.

Souped-up airplane: Inside EZ-Rocket's cockpit, three gauges (right) monitor oxygen and alcohol rocket fuels and helium pressurant.

Fuel feeder: Bottles of pressurized helium push liquid oxygen and alcohol fuel through feed lines of an EZ-Rocket motor.

deployment for research and communications and jump-start space tourism. Over a longer time frame, successor craft might provide a New York City–Tokyo passenger flight that takes less than three hours. And because breaking free of Earth's gravity is the largest cost of every space mission, cheaper launches are essential prerequisites for such visionary ventures as space-based solar collectors that beam energy to Earth 24 hours a day and precious-metals mining from asteroids.

Of course, people have tried for decades to realize the vision of a reusable rocket plane, with little success. "Rocket science has become synonymous with advanced technology, but the fact of the matter is that there has been very little in the way of new development of rockets since the early 1960s," says Xcor Aerospace president Jeff Greason, a former Intel executive. What's different now, he and others say, is that even before Columbia broke apart on February 1, people were actually starting to build and test new designs. Indeed, more than two dozen companies worldwide, not to mention NASA and other national space agencies, are developing rocket planes *(see "Space Visions," p. 48)*. With the loss of the Columbia and the subsequent grounding of the remaining shuttles, the number of developers and the urgency of their task are likely to grow. "The need to find some way to get new technologies and new approaches to space transportation is probably a lot clearer than it was before," Greason says.

Many private players are spurred by the prospect of capturing the $10 million X-Prize. This bounty, offered by a St. Louis, MO-based foundation funded by space tourism boosters, will be awarded to the first privately financed rocket craft that carries three people to the edge of space (an altitude of at least 100 kilometers), returns them safely to Earth, and does it again within two weeks. Already, 24 players have signed up to try.

But $10 million is a drop in the bucket compared to the real prize: space tourism. Last year a NASA-commissioned poll concluded that if reliable craft were available, 15,000 wealthy thrill seekers annually would sign up for suborbital flights costing about $50,000 each. That represents a $750 million market. And while it would not equal today's principal space business of launching satellites—in 2001, 39 launches worldwide generated nearly $3.3 billion in revenues—it might mark the start of something far bigger. "Space tourism has the potential to grow into a major new industry as important as civil aviation," says Patrick Collins, an economist at Azabu University in Fuchinobe, Japan, and a longtime advocate of space commercialization. In the near term, he adds, "There is no other application of space with even remotely similar potential." And whether or not such a market materializes quickly—it's possible the chilling images of Columbia breaking apart will make would-be space tourists nervous for years to come—the technology itself is clearly maturing. Last November the report of a presidential commission on the U.S. aerospace industry said reusable launch vehicles that could, at the least, substantially lower the costs of putting satellites into space are "well within our grasp in this decade."

HISTORY OF FAILURE

Creating reusable rocket planes should have been NASA's job. But NASA's effort—the X-33, an ambitious concept for a reusable rocket plane that by 2005 was supposed to demonstrate technologies that could eventually replace the space shuttle program—became the biggest white elephant ever produced by the U.S. space program. Between 1997 and 2001 almost $1.3 billion was spent on the hydrogen-powered craft, and there's virtually nothing to show for it. Fatefully, NASA chose a plan that employed a host of technically challenging (read: risky) technologies—including unique rocket engines, fuel tanks, and heat shields—and a complex vehicle design. Each of those technolo-

gies would have had to work for the craft to successfully unseat the space shuttle fleet—now more than two decades old—for missions that include ferrying astronauts to the International Space Station and launching scientific payloads such as the Hubble Space Telescope.

But one part, a composite liquid-hydrogen fuel tank built by Lockheed Martin, failed in tests. In 2001 NASA, facing the prospect of waiting another year for a new version, "walked away from the effort and started something new," says Lori Garver, a former NASA associate administrator. "Every time you do that, you lose ground." Now, two years after the X-33's cancellation, NASA's still largely undefined new effort is not expected to produce a space shuttle replacement in less than two decades. However, there will undoubtedly be pressure post-Columbia to accelerate that timetable.

One result of the X-33 debacle was to put a serious damper on private investment in the field. Conventional wisdom held that if NASA couldn't build a reusable rocket, no one could, says Collins. But the world lacks a rocket plane "not because it's difficult to build," he says. "It's just that virtually all rocket research has been done by a monopoly government agency." Buzz Aldrin, who in 1969 became the second man to walk on the moon, says the United States simply lacks a coherent national program for developing affordable launch technology. Although Columbia's fate could sharpen the focus, Aldrin says that for the time being anyway, "we're in a mess."

Into this mess arrive Xcor Aerospace and its competitors. Their vision: to build a new breed of rocket. Unlike every rocket launched so far, this craft would fly into space and return intact. (Some designs call for the rocket initially getting aloft by piggybacking atop a jet.) Even each of the space shuttles, the world's first and only reusable spacecraft, discards parts of the twin booster rockets and all of the huge external fuel tank with every launch.

Realizing this ambition looks relatively straightforward on paper. Rocket engines are basically combustion chambers with pumps that bring in fuel and oxidizer—oxygen or an oxygen-rich chemical that allows the fuel to burn even in the vacuum of space. They don't need a jet engine's high-speed turbofans and compressors, which provide oxygen from the air and account for about 80 percent of the engine's size, weight, and complexity. And as a result, rockets can fly far higher than jets, which cannot exceed altitudes of 16 kilometers because the air becomes too thin to burn aviation fuel and provide lift to their wings.

No one is saying that such upstarts as Xcor Aerospace can reach space in one step. Reaching orbit means attaining speeds of 27,800 kilometers per hour, carrying enormous amounts of fuel, and withstanding extreme stresses. Meeting these challenges will, by all accounts, take at least a decade. In the meantime, though, a lot can be learned while shooting for a much more modest goal: a rocket-powered craft able to reach the edge of space—an altitude of 100 kilometers—without actually going into orbit. Achieving that altitude requires a speed of about 4,500 kilometers per hour, not much faster than the top speeds of today's jet fighters, so designers of the rocket craft should be able to adapt the fighters' relatively tried-and-true systems and engineering procedures.

Xcor Aerospace president Greason says meeting the design goal is possible within the next few years. Six years ago he left the booming microchip industry because he saw the space business as being where computers had been back in the 1970s: a few companies controlled a market for big, expensive, exclusive hardware, and they were oblivious to the sea change being brought about by a few obsessed college dropouts who, working in garages, used off-the-shelf parts to produce amazing new personal computer systems. "It's very similar to the early days of the PC," says Peter Diamandis, chairman and founder of the X-Prize Foundation. "Suborbital vehicles that can make thousands of flights a year will create a marketplace by changing the perspective on space: it's not just for governments, but for the public."

SMALL, NIMBLE COMPETITION

Xcor Aerospace's EZ-Rocket is like those early PCs—simple, basic, and from the standpoint of the conventional aerospace business, practically microscopic. Its twin rocket

Now and later: The low-flying EZ-Rocket makes its public debut in November 2001 in Mojave,CA (top). Xcor's tourist-oriented Xerus concept (bottom) would graze the edge of space at 100 kilometers, its plume widening in near-vacuum conditions.

COURTESY OF XCOR

engines, fueled by alcohol and liquid oxygen, separately produce only one-thousandth the thrust of each of the space shuttle's three main engines. But unlike their shuttle counterparts, the EZ-Rocket engines can be fully controlled and even shut down and restarted in flight. Still, the EZ-Rocket is just a demonstration vehicle. The tiny craft is designed to rack up experience for building a two-seat suborbital space plane called Xerus, which is now in development.

For the Xerus, Xcor Aerospace is developing a rocket engine with five times the power of EZ-Rocket—an engine that can be throttled up and down through a wide range of speeds. A cluster of four or five such engines would lift the rocket plane to an altitude of 100 kilometers; then smaller rockets would allow the craft to maintain stability during an edge-of-space jaunt.

Xcor Aerospace is pursuing the two-person Xerus even though it will not meet the three-person criterion of the X-Prize. Prize or no prize, Greason, Rutan, and their handful of coworkers see plenty of financial incentive. Greason says the Xerus could launch a small satellite payload—about 10 kilograms—into a low orbit using a booster rocket on the satellite. Similarly small satellites are used for university research projects, which often must wait years to piggyback onto a larger satellite launch. And the Xerus itself could also be used for research such as collecting atmospheric data or carrying out engineering experiments that require brief periods of time in a zero-gravity environment.

The real target, though, is tourism. Greason says the Xerus could provide tourists with half-hour joyrides—three minutes of weightlessness and a chance to see the Earth's curvature and the darkness of space—then land on an ordinary runway. One Xerus alone, he says, could earn $24 million a year in tourist revenues on development costs of less than $10 million. Fueled by such visions, Xcor Aerospace hopes within three years to have flown and tested Xerus and readied the craft for production. "We decided to do the smallest steps we could, with as many of them as possible generating revenues," Greason explains. If Xerus works and tourist profits roll in, he says, the company's developers would begin to tackle the ultimate task—getting into orbit.

The idea of "smallest steps," of course, has a certain historical resonance when it comes to space technology. But while Xcor Aerospace focuses on the incremental approach, several competing companies are already pursuing the grand vision: a craft that can go all the way into orbit. One player is Pioneer Rocketplane in Solvang, CA. The company has designed a tourist or cargo-carrying rocket-and-jet hybrid called Pathfinder, which will take off with traditional jet engines. Once at a cruising altitude of about 5,500 meters, a fuel tanker plane will rendezvous with the Pathfinder and pump liquid oxygen into an empty tank on board the craft. Then, propelled by a combination of liquid oxygen and kerosene, the Pathfinder will light its rocket motor and soar to an altitude of 139 kilometers, where it could also release an unmanned upper stage to deliver a 2,280 kilogram payload into orbit.

Like Xcor Aerospace, Pioneer is starting with a smaller version—the Rocketplane XP—which will compete for the X-Prize. Though neither the XP nor the Pathfinder has reached even the prototype stage, Pioneer Rocketplane is considered a serious player. Its CEO, Mitchell Burnside Clapp, was responsible for an Air Force design of an airplanelike reusable rocket that later evolved into the Pathfinder concept. Because of that design, Pioneer Rocketplane is a leading competitor for a Defense Advanced Research Projects Agency project to develop an inexpensive rocket-propelled satellite launcher. (The agency was expected to announce the award of two final design contracts on March 1.)

Most of the reusable-rocket players are thinking in terms of carrying people—both pilots and tourists. But Germany's Astrium is expressly leaving out human cargo. Instead, it is developing an autonomous rocket craft called Hopper, designed to provide cheap satellite launches. The first step in this direction is the Phoenix, a one-sixth-scale version of the Hopper. The Phoenix is mainly a test bed for autonomous landing technology. The craft's designers are incorporating laser-based altimeters—

Space Visions

A sampling of private and government players developing reusable rocket technology

ORGANIZATION	LAUNCH TECHNOLOGY	PROPOSED TIMETABLE
Xcor (Mojave, CA)	Xerus: two-person suborbital rocket plane that takes off and lands on a runway; powered by four or five rocket engines	Ready for commercial tourist flights in three years
Pioneer Rocketplane (Solvang, CA)	Rocketplane XP: four-person suborbital rocket plane that takes off and lands on a runway; powered first by two jet engines, then two rocket engines	Ready for initial test flights in two years
Astrium (Bremen, Germany)	Hopper: two-stage reusable unmanned rocket plane launched from rails; powered by two rocket stages; lands autonomously on runways	Test of scaled-down prototype in 2004; full-scale craft ready in 15 to 20 years
NASA (Washington, DC)	Orbital Space Plane: three- to five-person rocket craft for travel in orbit to International Space Station	Version that could be launched from an expendable rocket ready in 10 years; fully reusable Earth-to-orbit craft ready in 20 years
Canadian Arrow (London, Ontario)	Canadian Arrow: three-person suborbital rocket plane; first stage powered by one liquid-fuel rocket engine; second stage, with crew cabin, powered by four solid-fuel rocket engines; parachute descent to water	Ready for first flight later this year
Advent Launch Systems (Houston, TX)	Three-person rocket plane launched from a floating position in water using single rocket engine; glides to water landing	Under construction, possible test flight this year

Readying reusable rockets: Private efforts to develop reusable rocket technology range from the 16-meter vertically launched Canadian Arrow (left) to the airplanelike Rocketplane XP (top right), which would use runways. Both are geared to space tourism, but the Hopper (bottom right) would provide unmanned satellite launches *(see "Space Visions," p. 48)*.

COURTESY OF CANADIAN ARROW; COURTESY OF PIONEER ROCKETPLANE/TOM BROSZ; COURTESY OF ASTRIUM

altitude sensors—and digital Global Positioning System equipment together with intelligent-navigation algorithms that enable the craft to make a gliding runway landing without help from humans or equipment on the ground. The first test of the vehicle, which is under construction, is expected next year: a helicopter will drop the Phoenix from an altitude of about 1,400 meters, leaving it to land on its own. Astrium estimates that the full-size Hopper could launch satellites in 15 to 20 years, at half today's launch costs.

And NASA isn't sitting on the sidelines. Although the exact shape of a successor program to the ill-fated X-33 is still being worked out by agency administrator Sean O'Keefe, who took the helm in late 2001, NASA had begun to fashion long-term plans for a bigger, more ambitious craft even before the Columbia disaster. The Orbital Space Plane is just a blank sheet of paper now, but the idea is that it would be ready to deliver crew and small amounts of cargo to the International Space Station by 2012.

If it does fly by 2012 or sooner, the Orbital Space Plane would get to orbit atop a conventional expendable rocket. But NASA hopes eventually to replace that rocket with a reusable system. To do this, researchers at NASA's Marshall Space Flight Center in Huntsville, AL, are simplifying and streamlining rocket engine design and incorporating built-in diagnostic systems to detect problems such as cracks, leaks, and stuck valves. Such systems would yield tremendous savings compared to the space shuttles, whose engines are dismantled and inspected after every mission by hundreds of engineers. "The goal is to bring rocket engine reliability into the same category as today's jet engines," says Garry Lyles, who is in charge of propulsion systems for NASA's program to develop technology for future launch vehicles. Right now anyway, NASA's plans call for a reusable space-shuttle replacement by 2025.

PRIVATE PUSH

Despite its poor track record with rocket planes, NASA remains a serious long-term competitor. But the agency's somewhat leisurely timetable has left the field wide-open for the private sector. And excitement about the potential for small companies to actually produce a reusable rocket craft is growing. An X-Prize victory by one of them would dispel skepticism and jump-start investment too. "It's a psychological step," says Rand Simberg, an aerospace engineer and consultant. "The little companies are going back and doing it like it should have been done in the first place."

Indeed, anticipating the ability of small companies to blaze new paths, one firm is booking tourist flights on rocket planes that exist today only on paper. Space Adventures, of Arlington, VA, already sends tourists on zero-gravity airplane flights in Russia, and it arranged Russian space flights—costing $20 million apiece—to the International Space Station for U.S. businessman Dennis Tito in 2001 and South African tycoon Mark Shuttleworth last year. The company has contracted for 600 Xerus flights and taken deposits from more than 100 customers.

"We've been impressed with Xcor's team of people and their ability to produce actual flying hardware and to carry out demonstrations on a low budget," says Eric Anderson, president of Space Adventures. And though Anderson initially feared that Columbia's frightening demise might cause some of his customers to think twice about space travel, none had asked for a refund in the first few days after the shuttle was lost—a fact he says shows a strong human commitment to space flight. Instead of scaring people off, he adds, what happened to Columbia "will serve as a wake-up call. Ten years from now, people will feel safer, will be safer" going into orbit as a result of improvements that will inevitably result from the investigation of the accident.

Space Adventures' backing of Xcor and other rocket companies provides a synergy that might be crucial for realizing the decades-old visions of reusable rockets, says Bruce Lusignan, an electrical engineer at Stanford University and director of the Center for International Cooperation in Space, a worldwide consortium of universities. He says space-related tourism revenues could finance a new generation of tourist-oriented launch vehicles, and "that might be the core to building the capability up. That might be the right way to go." And that means the EZ-Rocket—that unimposing test vehicle at the vast Mojave Airport—just might end up being the first PC of a new space age. TR

Clean slate: Craig Venter is writing an all-new genome, letter by letter.
PHOTOGRAPH BY ERIKA LARSEN

LIFE MADE TO ORDER

Scientists are taking genetic engineering to the extreme, creating new genomes from scratch. The result could be artificial life forms designed to churn out novel drugs or turn pollution into energy.

BY ALEXANDRA M. GOHO

For the last few decades, scientists have been intently decoding the genes of dozens of organisms, from bacteria to humans. The effort, which culminated in 2000 with the deciphering of the human genome's roughly thirty thousand genes, reflects researchers' increasing adeptness at "reading" the language of DNA. It's a biological literacy that has meant dramatic advances in understanding the genetic basis of health and disease, bringing with them the promise of safer and more effective drugs.

But now a small group of researchers are looking to a far more ambitious goal than simply reading the sequence of genetic material: they are attempting to write entirely new genomes from scratch. In essence, they hope to create new synthetic forms of life, the likes of which have never before existed, by painstakingly spelling out exact sequences of DNA that hold all the instructions for the new organisms.

It is biotech's most brazen attempt, so far, to play God. So the fact that Craig Venter, the legendary self-aggrandizing visionary of genomics, is leading the charge should come as no surprise. After all, it was Venter, then the president of Celera Genomics, who headed the controversial private effort to sequence the human genome—and to do so ahead of the public Human Genome Project. Now through the Rockville, MD-based Institute for Biological Energy Alternatives, a nonprofit organization Venter launched last April, he is gearing up to build a synthetic bacterium, by first writing out its genome. It's a project that would not only help meet the center's goal of creating high-utility microorganisms specifically designed to mop up carbon dioxide, say, or produce hydrogen fuel with the utmost efficiency; it's a project that could also upend genetic engineering itself.

Venter's objective is not merely to tweak existing life forms by inserting genes that confer specific traits—the main tactic in conventional genetic engineering. Instead he wants to assemble an entire genome, DNA letter by DNA letter, putting together only the genes he wants: those necessary for an organism's survival and those that will allow it to carry out a desired task. "The long-term advantage of creating an organism from a chemically synthesized genome is that it allows complete flexibility of design," says University of North Carolina biologist Clyde Hutchison. No longer limited to nature's repertoire, researchers could create a wide variety of synthetic organisms, each made to perform a specific chore, such as sopping up oil slicks or producing a plastic. And because such a bacterium would devote most of its energy to its assigned job, it could, in theory, be much more efficient than a counterpart made via conventional genetic engineering.

Building such an organism "would be a momentous achievement," says Eugene Koonin, an evolutionary biologist at the National Center for Biotechnology Information, a part of the National Institutes of Health. But, Koonin points out, creating life from scratch presents a few daunting challenges. Even a simple single-celled organism such as a bacterium can have hundreds of thousands or millions of DNA letters. And even if scientists do figure out the exact sequence of DNA that would create the organism they want, they would still have to figure out how to "write" those letters in long stretches of DNA. Though researchers routinely synthesize short DNA strands, today's DNA-making machines can't handle anything longer than a hundred letters or so. And piecing together an entire genome from such tiny fragments is a monumentally time-consuming, error-prone task.

Still, despite the audacity of the endeavor, Venter is not alone in his ambition to rewrite the language of life. A small cadre of researchers in academia and industry are working out the details of technologies that could make genome writing routine; one such tool is a machine capable of synthesizing, automatically and with high accuracy, genome length stretches of DNA. And while those scientists are honing their DNA-writing skills, others are looking to transform the genetic language itself by adding entirely new letters to the DNA alphabet—thus creating the potential to give organisms abilities not seen in nature. "The program got written four billion years ago," says MIT computer scientist Tom Knight, who studies the interface between biology and computing. "It's time to rewrite the program."

MINIMALISM

The roots of Venter's ambitions lie in an earlier effort called the Minimal Genome Project. In the mid-1990s, researchers at Venter's Institute for Genomic Research sequenced the first two complete genomes—both bacterial. Armed with new information on the genes that make each species unique, the researchers were curious to see which of those genes were necessary to sustain life. It wasn't just curiosity that drove the project though. If researchers could identify those genes, they reasoned, they would be able to model the most basic of cell activities. "That would be helpful in understanding more complex cells and in designing new ones," says Hutchison.

The program of life—the system of DNA, genes, and genomes that governs every living thing—was written four billion years ago. It's time to rewrite the program.

The team started with a lowly bacterium called *Mycoplasma genitalium*, whose tiny genome consists of just 517 genes made up of about 580,000 DNA letters. "I raised the question: Does the bacterium need all those genes?" says Hutchison, who had taken a sabbatical from the University of North Carolina to work on the project. By selectively disabling different genes, the researchers discovered that only 265 to 350 were essential: few enough to make it conceivable that researchers could assemble the entire genome from scratch, though the endeavor might take a decade or more.

But the group put the Minimal Genome Project on hold in 1999, while Venter focused on sequencing the human genome. Now he has revived the project—this time with a specific application in mind: creating artificial bacteria that could help provide cleaner sources of energy. Under the guidance of Nobel Laureate Hamilton Smith, who left Celera last fall to become the scientific director of the Institute for Biological Energy Alternatives, researchers will try first to build a minimal genome and place it inside a bacterial cell whose own genome has been

DNA assembly line: Egea's machine churns out genes in record time.
PHOTOGRAPH BY MISHA GRAVENOR

destroyed. The researchers' hope is that the synthetic genome will take over, and a new life form will be born. If they succeed with this preliminary experiment, the researchers will then begin to create organisms whose minimal genomes will be supplemented with additional genes that provide instructions for metabolizing carbon dioxide, say, or producing hydrogen fuel.

Not only does designing genomes from scratch allow researchers to engineer new organisms with extreme precision, Venter says, it also allows them to strip the cells of a host of natural functions needed to survive and reproduce in the wild. As a result, synthetic organisms would function only under tightly controlled or rarified conditions such as those inside a biological pollution filter on the smokestack of a fossil-fuel-burning power plant.

"By our back-of-the-envelope calculations," Venter says, "it wouldn't be that complicated to have a carbon dioxide scrubber, directly associated with those power plants, that captures all the carbon dioxide and converts it into something economically useful"—like a plastic. Or researchers could engineer bacteria that use methane from waste sites, for instance, to produce hydrogen fuel. "As far as I know, there is no existing organism that can either capture carbon dioxide or produce hydrogen efficiently enough with its existing metabolism to make it economically feasible," says Venter.

SPEED WRITER

For now, synthetic bacteria with custom-made metabolisms exist only on the blackboard, and it could take a decade before the chalk dust gives way to living creatures. But there is growing evidence that, just maybe, it could happen.

Last summer researchers from the State University of New York at Stony Brook proved that it's possible to synthesize an organism—albeit one found in nature—from nothing more than genome sequence information and chemicals in a test tube. Molecular biologist Eckard Wimmer and his colleagues used a

Letter man: Glen Evans makes long strings of DNA letters fall into line.
PHOTOGRAPH BY MISHA GRAVENOR

combination of DNA synthesizers and brute force to reconstruct in DNA the 7,500-letter-long polio genome sequence. Next, they converted that sequence into RNA, a biochemical cousin of DNA that makes up many viral genomes, combined that RNA with enzymes and other molecules in a test tube, and watched as whole polio viruses assembled spontaneously. It was the first time scientists had ever synthesized a virus—or any other organism for that matter—from scratch.

When the work was announced, many scientists called it a publicity stunt, arguing that the Stony Brook team had chosen to build a dangerous microbe in a bid for headlines. But the work did highlight a very real technological problem: assembling long strands of DNA by conventional means is an almost prohibitively time-consuming task. Researchers like the ones at Stony Brook first synthesize short fragments using conventional DNA synthesizers. Such machines use a complicated series of chemical reactions to attach each DNA letter to the next. Because errors can occur at each step, the longer the fragment, the more errors it contains; so researchers typically limit fragments to fewer than 80 letters. To assemble longer DNA strands, they toss the fragments sequentially into test tubes, together with enzymes that link the fragments end to end. This process introduces a multitude of tiny, single-letter errors though. Detecting and correcting those errors adds more work and more time to the job. Had the Stony Brook team chosen an organism with a genome longer than 7,500 letters, it might still be working on the project.

But that might be about to change. Glen Evans, CEO of San Diego, CA-based Egea Biosciences, thinks his company has a solution—one that could help propel the idea of engineering wholly new organisms into reality. "It took the polio researchers two years to synthesize the virus," says Evans. "We could have done that in less than a week."

The source of Evans's bravado is his company's newly developed machine, which can rapidly synthesize long strands of DNA with relatively good accuracy: the device makes a mistake only once for every 10,000 DNA letters, or bases, Evans says, whereas conventional techniques typically have an error rate of one in 100. Right now Evans's DNA-writing machine is accurate enough to make several genes at once, but he hopes to get the error rate down low enough to make the larger DNA strands that are required for building entire genomes. Evans first conceived of the technology at the University of Texas Southwestern Medical Center, where he was director of the Human Genome Sequencing Center. When researchers completed a draft of the human genome, he says, "we realized we had read the genetic code, but we didn't have the ability to write the genetic code."

To fill that gap, he built a gene-writing system that combines hardware and software. Using the software, a researcher can design a protein—a new drug, for instance—on a computer, which in turn determines the sequence of DNA bases needed to encode the protein. "It's kind of like word processing for DNA," says Evans. The hardware, essentially a robotic chemistry lab, assembles long stretches of DNA automatically, circumventing what would otherwise require endless hours of tedium for humans. The machine first synthesizes fragments of the gene, each measuring 50 to 100 letters long, and arrays the fragments into tiny wells. It then grabs each fragment in sequence, attaching one to the next with a customized cocktail of enzymes and ultimately producing the whole gene, which can amount to a few thousand bases. Evans says Egea has developed a prototype machine that, thanks to automation, can synthesize 10,000 bases in just two days. He says the technology could be extended to yield in a matter of weeks highly accurate strands 100,000 bases in length—long enough to make a very simple bacterial genome. Automation and robotics also allow for careful control of each chemical reaction in the process. That control, combined with the enzyme cocktail, helps keep long DNA strands largely free of the errors that plague conventionally made strands.

Though Venter and other researchers bent on creating synthetic organisms will still have a lot of scientific heavy lifting to do before they're able to design new genomes readily, technology like Egea's, says MIT's Knight, could lighten the burden of genome construction. And a handful of biotech companies are now also getting into the business of souped-up DNA synthesis. "Pretty soon, we won't have to store DNA in large refrigerators," says Knight. "We'll just write it when we need it."

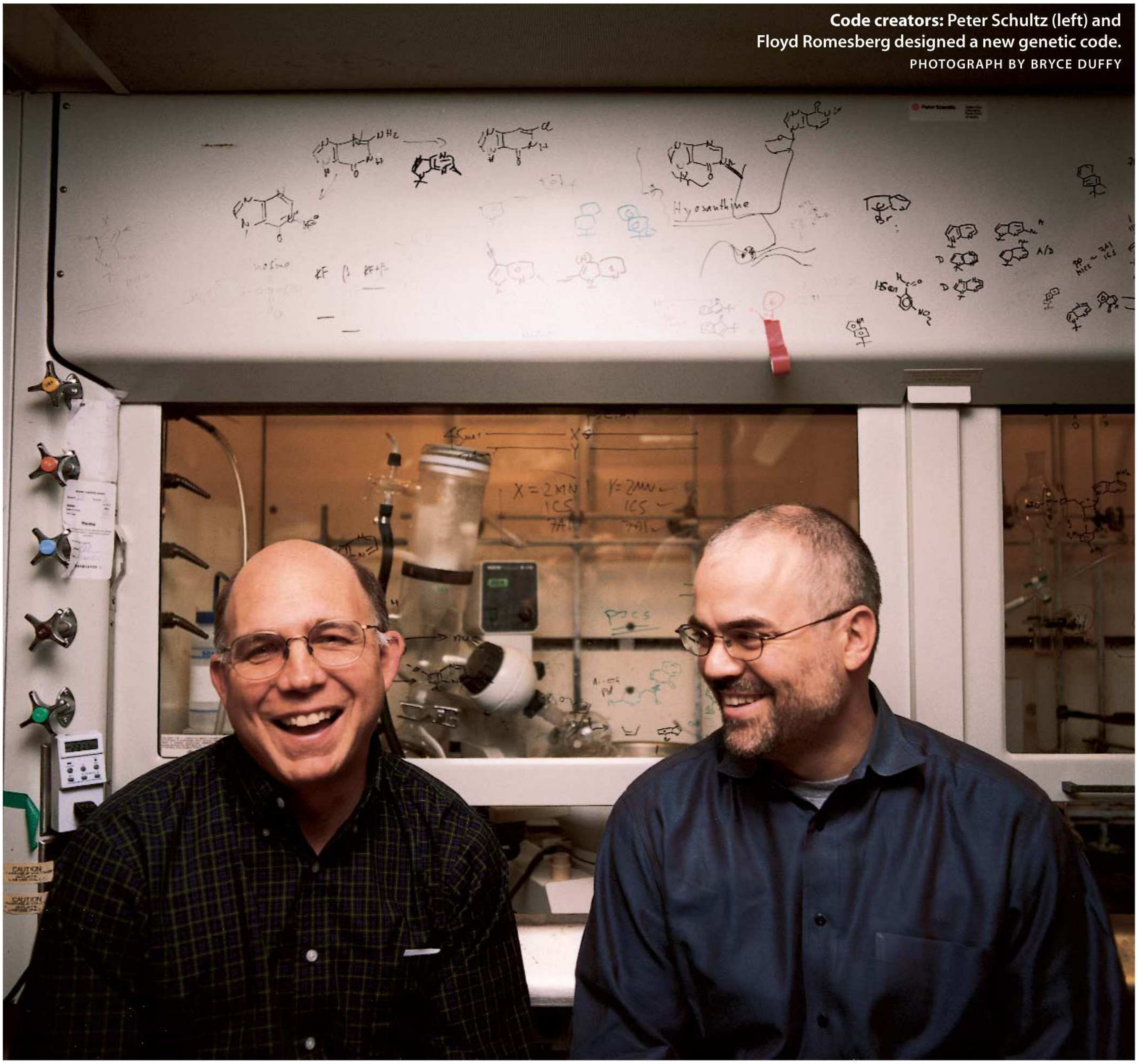
PLAYING WITH BLOCKS

While Evans and others are working on machines that could expand researchers' ability to write genes, chemists at the Scripps Research Institute in La Jolla, CA, are expanding the genetic alphabet itself. "Our repertoire of bases is naturally limited," to the familiar DNA letters A, T, C, and G, says Scripps chemist Floyd Romesberg. Because these letters tell an organism which proteins to make, the types of proteins that can be specified by the genome are limited as well. Getting, say, a bacterium to make novel types of proteins would require adding new DNA letters.

Synthetic-genome research raises the question, if God had worked on Sunday, and he had had more biological building blocks to work with, what would have been the outcome?

That's exactly what Romesberg's lab has done. Building on the pioneering work of biologist Steven Benner at the University of Florida, Romesberg and his colleagues have created a letter in the form of the chemical fluorobenzene. This artificial DNA letter looks nothing like a natural one, he says, so the challenge is to trick the cell's DNA replication and translation machinery into recognizing it. So far, the Scripps researchers have synthesized short fragments of DNA that incorporate the new letter and have successfully created an enzyme that can replicate the modified code. The next step is to design a system for translating the code into a completely unnatural protein—a novel drug, for instance.

To do this, Romesberg is collaborating with another Scripps chemist, Peter Schultz. While Romesberg's team was rejiggering the DNA alphabet, Schultz's lab was tinkering with another set of biological building blocks: the amino acids that form proteins. Living things use 20 amino acids, which are strung together as proteins, following instructions encoded in the DNA. Schultz's group created a bacterium that has 21, the 21st being a chemically modified version of a natural amino acid. Such synthetic amino



Code creators: Peter Schultz (left) and Floyd Romesberg designed a new genetic code.
PHOTOGRAPH BY BRYCE DUFFY

acids offer the chance to build new functions into proteins. "There's a huge range of chemical groups that we could put into proteins to make them do interesting things," says Schultz. He is, for instance, working on creating photosensitive amino acids which, in response to light, could trigger specific reactions in a cell.

What's more, the two Scripps teams are working to combine their techniques. The goal: to create cells with all the enzymes and other molecules necessary to translate DNA code that bears Romesberg's artificial letter into proteins that incorporate Schultz's artificial amino acids. The technology could have a huge impact on the development of new protein therapeutics, says Schultz. Protein drug researchers typically modify natural proteins—adding a specific sugar that binds to a cancer cell, for example—to increase their effectiveness. "But what these people are doing is kind of dirty chemistry," says Schultz. Treating these extra chemical groups as artificial amino acids and directly encoding them in a synthetic gene would enable researchers to modify proteins with incredible selectivity and simultaneously create living factories that churn out the new proteins.

"We've removed a billion-year-old constraint on what we can do with proteins," says Schultz. "And so we're taking the point of view that if God had worked on Sunday, and he had more amino acids to work with, what would have been the outcome?" Would an organism with an expanded genetic code and amino acid inventory have an evolutionary advantage? Perhaps there is a reason why all known organisms share those 20 building blocks. "Is it just a chance of history that early life took this route?" asks Stephen Freeland, an evolutionary geneticist at the University of Maryland, Baltimore County. "Or is there more to it?"

If scientists could answer such big theoretical questions, Freeland says, it might be possible one day to discover on other planets life that might not otherwise be recognizable. And if the synthetic-genome technologies in the works at Scripps, Egea, Venter's institute, and elsewhere pan out, life right here on Earth could soon look a little less familiar—and a lot more diverse. TR

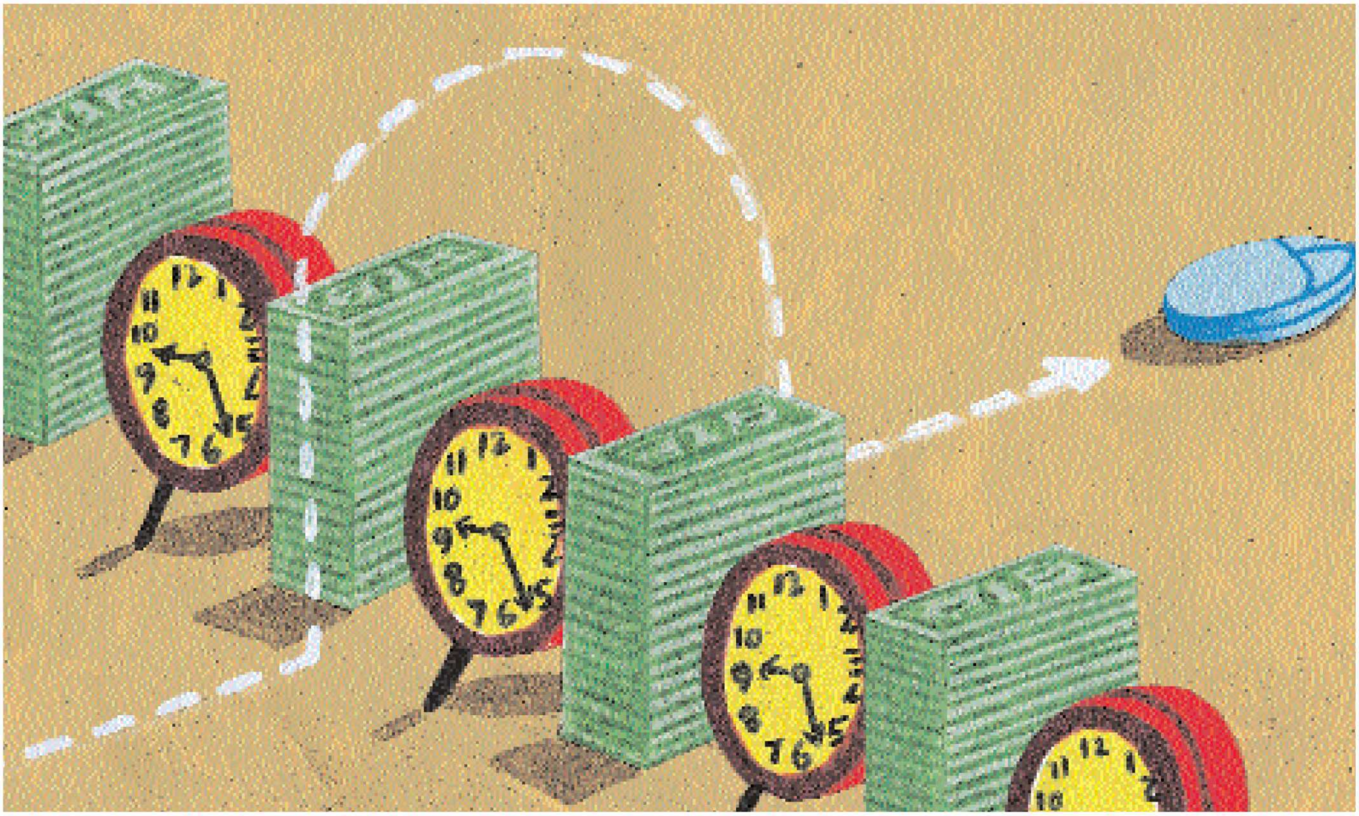
Paperless Medicine

FOR YEARS, DOCTORS HAVE RECOGNIZED THE POWER OF INFORMATION TECHNOLOGY TO TRANSFORM HEALTH CARE. SO WHY AREN'T MORE MEDICAL RECORDS COMPUTERIZED?

Doctors' lousy handwriting is infamous. Every day pharmacists stop customers to ask them what their prescriptions say, and patients pick up orders only to find that they've been given the wrong dosage or even the wrong drug. But those pharmacist misreads can mean more than mere hassles.

In a 1999 study, the Institute of Medicine reported that in 1993, almost 7,400 Americans died from medication errors. A decade later, such errors are still a major problem. GlaxoSmithKline, for example, has posted a notice on its Web site warning that patients with prescriptions for its antiseizure drug Lamictal have mistakenly received Lamisil (a medication for fighting nail fungus), Lomotil (an antidiarrheal), Ludiomil (an antidepressant), and other medications—sometimes with dire consequences.

BY ERIKA JONIETZ • ILLUSTRATIONS BY GENE GREIF



One basic change—using computers to order prescriptions—has reduced medication errors by as much as 80 percent in some hospitals. Motivated by such life-and-death statistics, a growing though still-small number of doctors and hospitals are weaning themselves from paper, using computers not just to order prescriptions and lab tests but also to track patients' conditions, medications, allergies, and test results. "We could make tremendous advances in improving health care with the technology that we have in hand," says Gilad Kuperman, associate director of clinical informatics research and development for Partners Healthcare System in Boston.

Those advances would be a welcome change from the messy, difficult-to-track record keeping that prevails in health care today. Typically, the primary care physician keeps one set of records, hospitals another, and each specialist yet another. And all of these medical histories are logged in old-fashioned paper "charts." Any information a patient forgets to tell one of his or her doctors—about a severe allergy to a medication, say,—simply doesn't appear in that doctor's record.

Indeed, much of the nation's health-care system is entering the information age kicking and screaming. While Amazon.com and grocery chains compile detailed records of customers' buying habits, only about 5 percent of U.S. primary care doctors store information about their patients electronically. Resistance to adopting the technology abounds, rooted in doctors' unwillingness to abandon decades-old ways of doing things and a perception that the benefits to the practitioners are not worth the costs. "McDonald's has a better record of what they've served all their customers than we have of our patients' medical histories," says Isaac Kohane, a Harvard University medical informatics specialist and endocrinologist.

Still, the medical world hasn't been able to entirely ignore the cheap and plentiful computing power and networking technologies developed over the past decade. The U.S. Department of Veterans Affairs now uses electronic records at each of its 163 hospitals, many of which are now essentially paperless. Increasing numbers of private hospitals and medical systems are implementing computerized patient records as well. About 1,500 primary care physicians and 11 hospitals use Partners Healthcare's medical records system to keep track of several hundred thousand patients. And in February, Kaiser Permanente, the nation's largest HMO, announced that over the next three years it would implement electronic records for all its 8.4 million members. As more doctors begin to train and work in such hospitals and realize the benefits of their systems, the hurdles to even wider adoption may slowly disappear. And as new genetic information drives medicine toward data dependence, electronic health records will become more than beneficial—they will be absolutely necessary. The medical databases of the 21st century will join the anesthesia of the 19th century and the antibiotics of the 20th as indispensable medical tools.

VIRTUAL VETERANS

At the South Texas Veterans Healthcare System, doctors and nurses use a client-server system that links workstations and PCs and provides a graphical interface for reading and entering patients' data. Each patient record includes such statistics as height, weight, and blood pressure; medical conditions (for example, diabetes); medications the patient is taking; and lab test results. Access to information throughout the VA's nationwide network of hospitals and clinics is one of the biggest benefits to clinicians, says Vikie Schwartz, assistant chief of the South Texas system's office of information technology in San Antonio. "We have a clinic in McAllen, which is about five hours

away. They can view the same chart that we can view here, at the same time," she says. If a patient from San Diego had a medical emergency while visiting San Antonio, the records from California would be accessible. Having lists of medications and test results so readily available allows doctors to avoid unnecessarily repeating tests or duplicating prescriptions, saving time and money.

The technology's benefits go beyond convenience for the medical staff: patients get better care. Take the case of a 70-year-old man who came to the Audie L. Murphy Memorial Veterans Hospital in San Antonio early last December. The triage doctor diagnosed his bad cough as pneumonia and admitted the man to the hospital. Using a PC on the ward to log into the network, the resident on duty was able to check the patient's medical history, including information from his last visit with a primary care doctor.

After assessing the information, the resident typed in instructions for the man's care using the computerized order-entry system: prescriptions for intravenous Levaquin (an antibiotic) and an inhaled bronchodilator, orders for a chest x-ray and blood tests and dietary instructions. The system helps decrease errors and holdups in the delivery of medication and fulfillment of tests. "You make sure that the order is complete," says Schwartz. "And there's no delay in carting a piece of paper around." Once the lab results were ready, the doctor could have viewed them from any computer in the hospital. "People who get in and start to use the system begin to realize the power of what they have," says Gary Christopherson, who was formerly chief information officer of the Veterans Health Administration and is now senior advisor to the undersecretary for health in the VA.

PHYSICIANS' ASSISTANCE

The most compelling immediate advantage of electronic medical records is in their reduction of clerical errors. But once computers enter the picture, other benefits also become possible. Software can, for example, help doctors make better choices. So-called clinical decision-support programs can alert doctors to potentially dangerous problems with a drug or dosage, taking into account a patient's weight, diagnosis, other medications, allergies, and factors, such as kidney function, that can affect drug metabolism. If the pneumonia patient already had been taking Lamictal to prevent seizures, the software might have flagged the prescription for Levaquin, which can exacerbate seizure disorders.

Clinical decision support can improve patient care in other ways, too, by helping doctors hew to routine treatment guidelines. The software might, for example, suggest that patients who are older than 60 receive flu shots. Although this recommendation might seem obvious, it is easy for a busy doctor to forget. "Doctors are more likely to comply with prevention measures if they have decision support," says David Bates, a Partners primary care physician who has studied the benefits of electronic medical records. Kaiser Permanente has been experimenting with electronic records since the early 1990s, and so it now has the country's highest rates of mammography and Pap smear screening, according to Andy Wiesenthal, the lead physician on Kaiser's national implementation team.

Systems like the VA's also give health-care providers a powerful tool for viewing patient data. Paper records log a patient's medical history as a chronological narrative of office visits, ailments, and other medical information. Doctors have to flip through pages and pages of comments to discern trends in a patient's weight or test results—a task they may not have time to do routinely. Using a patient's electronic record, clinicians can display such data by category; this makes it easier to spot trends over many years and allows doctors to manage the patient's health better. "Being able to look at data, at blood pressures that may be spanning seven, eight, nine years, and to see it with just a single click of the button gives a lot of power back to clinicians," Christopherson says.

This ability goes beyond mere text data. A growing number of electronic medical records incorporate digitized images from tests such as x-rays and MRIs. In fact, text can comprise as little as 1 to 2 percent of the data in a computerized record. Having the image data as a permanent part of the record means they are always available when needed. Partners Healthcare, for example, already includes all computed tomography and MRI images as part of a patient's record, and x-rays are being converted "very rapidly" into digital form, says Bates. "I can look at the actual image myself from a remote location via a secure Web site, without having to actually go down to radiology and have them try to find the film—which they were often unable to do."

Computerized records can also help patients take a more active role in their own health care. One of the most far-reaching patient-access programs is PatientSite, a secure Web portal run by CareGroup Healthcare System, a network of almost 2,000 doctors and six hospitals in Massachusetts. About 10,000 patients use PatientSite each month to schedule appointments, review their medical histories, request prescription refills, and even view results of lab tests. "The same sort of things you can do with Fleet Bank, you now can do with your doctor," says John Halamka, chief information officer of Harvard Medical School and CareGroup.

For the most part, the information in electronic medical records is stored not in

The Record Keepers

INSTITUTION	PROJECT/TECHNOLOGY
CareGroup Healthcare System (Boston, MA)	PatientSite, a Web site that gives patients 24-hour access to their medical records
Cedars-Sinai Health System (Los Angeles, CA)	Campuswide deployment of 802.11b wireless network, providing access to electronic records
Kaiser Permanente (Oakland, CA)	Implementation of electronic medical records and patient access for all 8.4 million members through a set of databases sharing a common interface
Regenstrief Institute (Indianapolis, IN)	Access through a Web browser to patient data for emergency rooms in 13 hospitals
U.S. Department of Veterans Affairs (Washington, DC)	Separate electronic medical-records systems deployed at all 163 VA hospitals and many outpatient clinics

a single database but in numerous loosely connected systems: labs, billing offices, hospital admitting desks, and radiology departments, for example. But the same communications protocols that undergird the Internet are also helping to bring about seamless operations. Cedars-Sinai Health System in Los Angeles has created Web "wrappers" that pull data from about 20 computers to create the illusion of an integrated record. It is far easier to implement such a system than to build a unified repository of records that serves every department in the hospital. "The Web is this natural glue," says Halamka at CareGroup, which has a system similar to the one at Cedars-Sinai. "It's very easy for docs to navigate and coalesce all the information about a patient—no matter where the care is delivered—into one single, virtual medical record."

TAKE A NUMBER

Dramatic increases in computing power and connectivity, combined with studies that prove the benefits of using electronic medical records, have left doctors with little excuse for failing to adopt computerized record keeping, says Daniel Masys, director of biomedical informatics at the University of California, San Diego Medical School. Yet a 2002 study sponsored by the Kaiser Permanente Institute for Health Policy reported that the health-care industry spends only 2 percent of its revenues on information technology, in contrast to the 10 percent spent by other information-intensive businesses. And a 2002 report by the Institute of Medicine called on the U.S. government, health-care organizations, and payers to commit to building a national health-information infrastructure that would "lead to the elimination of most handwritten clinical data by the end of the decade." What will it take to get from here to there?

"We're in a very strange cultural warp," says Masys. "The system as it is now is optimized for the autonomy of individual practitioners." Electronic records, with their emphasis on practice guidelines, force doctors to alter their workflow and push them toward standardized care. Some doctors complain that the systems are an "intrusion into the practice of medicine," says John C. Joe, director of medical informatics at Baylor College of Medicine in Houston. "Most of the physicians here are at the tops of their professions," he adds. "They feel that their clinical judgment and the skills they have acquired are sufficient" for patient care.

Doctors also worry about time. When systems are first installed, using them slows things down. "Our surveys have shown that using a computer takes 50 to 100 percent more time" than traditional pen and paper, says Peter Waegemann, executive director of the Medical Records Institute, which advocates electronic medical records.

Electronic medical records provide access to patient data anytime, anywhere. The systems reduce dangerous errors and speed up the delivery of care.

But hospitals that use electronic medical records find that doctors who adapt to the systems don't want to go back. And increasing implementation is slowly changing attitudes. The VA, for example, is one of the nation's largest physician-training grounds; its system influences the way thousands of health-care providers work. "We have a whole flood of physicians and nurses and other people coming through training programs, touching the system every day, and then going on to other settings," says the VA's Christopherson. These medical practitioners especially like the ability to access data anytime and from anywhere in the hospital, he says. "People are asking, 'Why can't we have a system like the VA?'"

Even supporters of electronic records, however, face the issue of expense. The technology offers better care for patients and lower costs for insurers, but individual doctors often bear the financial burden. A computerized order-entry system alone can cost a hospital $5 million, according to Halamka. John Glaser, Partners' vice president and chief information officer, estimates that simply maintaining its system costs $5,000 to $10,000 per doctor each year. Most smaller hospitals cannot accommodate such expenditures.

The problem is even more acute for a solo or small group practice that could have to pay $60,000 to $70,000 for a commercially available system that might require continual outlays to keep it up-to-date. From a doctor's standpoint, says Glaser, adopting the technology can seem like all risk and little reward. "It's expensive, it's disruptive, and it's hard to get used to," he says. And during the three to six months it takes for most doctors to get used to a new system, productivity can fall by as much as 20 percent, Glaser says.

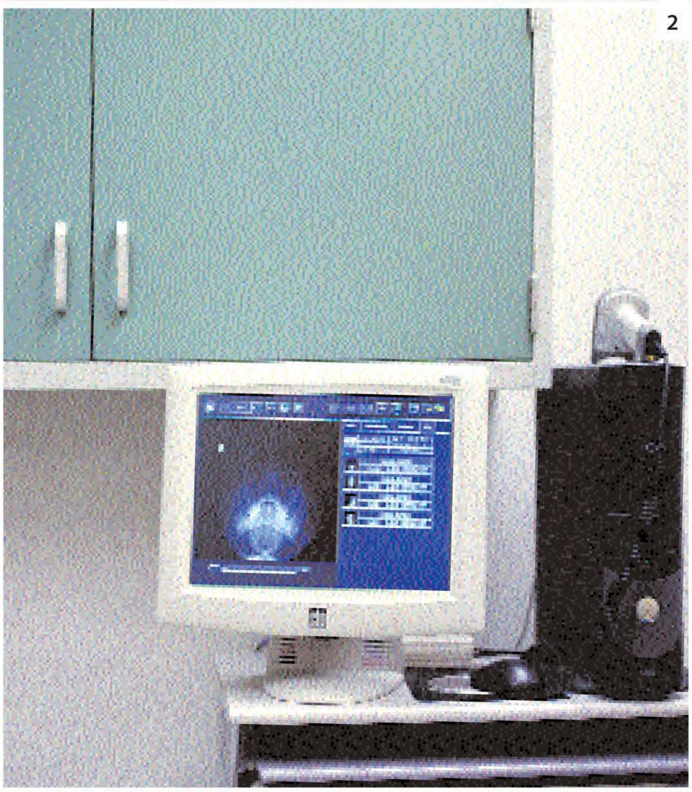
The health-care system itself provides little motivation for adopting the technology. What's needed, Glaser believes, is a breakthrough in motivation. One possibility would be for insurance companies to offer higher compensation to doctors who use electronic records systems that meet basic standards—in essence, a reward for providing higher-quality care. Some major companies already have started to exert such pressure. The Leapfrog Group is a coalition of such major corporate-insurance purchasers as AT&T, General Motors, and IBM; its members make health-care purchasing decisions on the basis of hospitals' compliance with specific safety measures, including computerized order entry.

Direct federal grants to help physicians implement computerized records could provide an even bigger boost. The countries with the most extensive use of electronic medical records—England, Australia, and Sweden—have significant government programs that fund doctors. In England, 99 percent of general practices use an electronic records system.

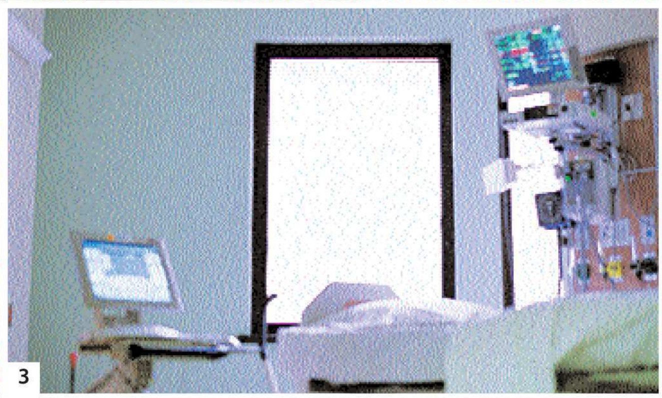
STANDARD CARE

Most medical-informatics systems are proprietary. This lack of standards is "the number one hurdle" in achieving wider adoption of electronic medical records, says Waegemann. Creating uniformly accepted medical and lab vocabularies, as well as protocols for data exchange, would make it possible for far-flung medical-records systems, lab computers, and insurance networks to talk to one another. Doctors and patients could access medical histories, even as patients move from doctor to doctor and state to state.

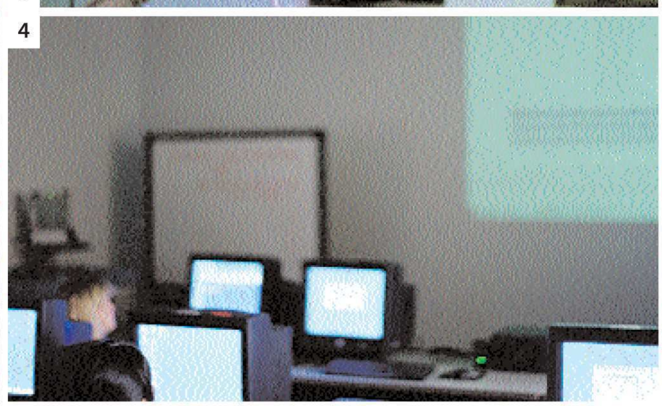
1



2



3



4

PAPERLESS VISTAS

PHOTOGRAPHS BY LEE BLANKENSHIP EMMERT

Doctors and nurses in the South Texas Veterans Healthcare System use an array of elements of the Veterans Health Information Systems and Technology Architecture, or VISTA, in their daily care of both outpatients and hospitalized patients. **1.** "Med carts" equipped with computers and bar code scanners improve medication safety. Nurses scan bar codes on drugs and on patients' wristbands, matching drugs with the right recipients. **2.** A digital retinal scan taken in the outpatient ophthalmology clinic becomes part of a patient's computerized record. **3.** Wireless laptops on rolling carts can be moved into hospital rooms, so doctors and nurses can access records and enter notes on the spot. **4.** New staff members learn how to use VISTA in a specially equipped training room.

A number of organizations, including Waegemann's Medical Records Institute, are pushing hard to establish such standards. The Markle Foundation, a New York City–based philanthropy that promotes information technology for the public interest, has created Connecting for Health, a public-private collaboration, to advance national clinical-data standards. Government health agencies could also help in the drive to establish such standards; the VA has embarked on a joint venture with the U.S. Department of Defense to do just that. Because the medical records of active military personnel eventually become the histories of veterans, the two departments are collaborating to create fully interoperable systems—possibly with a single user interface. The initiative goes even further, reaching across the federal government and into private health-care organizations such as CareGroup and Kaiser Permanente. Standards arrived at cooperatively by the federal government and the private sector "will become the tipping point to creating at least national standards, if not potentially helping to create international standards," says VA advisor Christopherson.

Nailing down standards should bring another major gain: helping electronic medical-records systems comply with federal privacy regulations. That benefit alone could be huge. It's possible, says bioinformatics specialist Masys, "to create a high-assurance, high-security architecture built on the fundamentally unsafe infrastructure of the Internet." For example, the technology used to encrypt financial information on Web merchants' servers can be used also to protect confidential medical data. The real challenge lies in making sure these measures are properly implemented. Connecting for Health aims to help physicians and hospitals achieve this goal by identifying and promoting procedures that address privacy and security issues in electronic medical-records systems. With such practices in place, a hospital would be no more likely to run an insecure computer system than to allow surgeons to operate without washing their hands.

ELECTRONIC CONNECTIONS

As consumers continue to demand a bigger role in—and better quality from—their medical care, physicians will become more inclined to adopt electronic medical records. As they do so, benefits beyond those for individual patients will emerge.

Consider, for example, the national effort to beef up defenses against a terrorist attack involving biological agents. Should victims of a bioweapon begin to show up in hospitals and clinics throughout New York City, it could take days or weeks for physicians to realize that the patients at the various facilities were suffering from a single attack. Software designed to mine data from computerized records could spot the trend quickly, setting off alarms. Recognizing the power of the technology, in January the U.S. government announced a multimillion-dollar effort to use information gleaned from medical databases to monitor for disease outbreaks and bioterror threats in a half-dozen or so cities.

The power of electronic records to connect the dots has implications far beyond the war on terror. As biomedical researchers discover more about the molecular bases of disease and the connection between genetics and health, medicine will become more and more dependent on volumes of data on individual patients. Medical records in the coming decade will incorporate not just demographics and medication histories, but also DNA sequences and gene expression profiles, which describe specific genes that are active in various tissues in the body. IBM Life Sciences, for example, has embarked on collaborative efforts to manage just such medical data in a pilot project with Hadassah Hospital in Jerusalem, Israel. IBM researchers have created an integrated medical record that contains such standard data as test results, physician observations, and lists of prescribed medications, as well as information on the patients' genomes.

"Health care will increasingly be a molecular-medicine view of health and disease," says Masys. He cites as emblematic one research project that measures the gene expression levels in prostate tumors. Finding correlations between gene expression and the disease's progression would enable doctors to provide more effective diagnoses and treatments but would require cutting-edge bioinformatics software. "The fusion of both computing technologies and biotechnologies is really the remarkable difference of our time," Masys says. "If people look back a hundred years from now, they will see this dramatic turning point in human affairs with respect to health."

Electronic records will enable that transformation, helping doctors make sense of mountains of data and enhancing the quality of health care. And now, with a big push from some of the nation's biggest health-care providers, the technology's stay in the waiting room may be nearing an end. TR

In the future, medical records will incorporate genomic information. Software could predict patients' responses to a treatment on the basis of their specific genetic profiles.

DEMO

Imagine a computer that listens to you, watches you, and gives you what you want exactly when you want it. **Alex Waibel** is building that computer. **Photographs by Beth Perkins**

The Observant Computer

Alex Waibel is disappointed in his computer. "It doesn't care what I do and who I am and where I sit," says the director of Carnegie Mellon University's Interactive Systems Laboratories. "It just doesn't do anything until I do something—until I hit some button." Splitting his time between his lab at Carnegie Mellon and a sister lab at Universität Karlsruhe in Germany, Waibel is working to free humans from that forced interaction with machines. His model for the ideal computer? "A good butler or a good secretary—someone who invisibly hovers in the background, guesses your very needs, and serves them up before you even ask." That way, he says, humans would be free to interact with other humans and, as he puts it, "do the human thing." Computers would observe what the humans were doing—and understand it sufficiently to guess how to help the humans out. Sitting at a table in his office with *Technology Review* senior editor Rebecca Zacks, Waibel explains how that might play out. "I want to talk with you and then," he says, craning his head toward his desktop machine, "say, 'Oh, by the way, write a letter to so and so and tell him I can't do the review.' But how should the machine know that I'm now talking to it and not to you? If I say something about deleting the files, I don't want to have my computer go off and delete all the files. It needs to know who is being addressed." That's just one of a number of obstacles standing between Waibel and the computer of his dreams. He told Zacks about a few more hurdles and showed her what his team is doing to clear them.

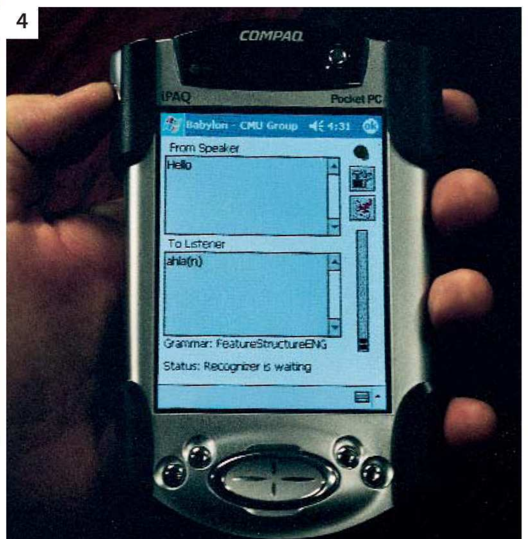
1

2

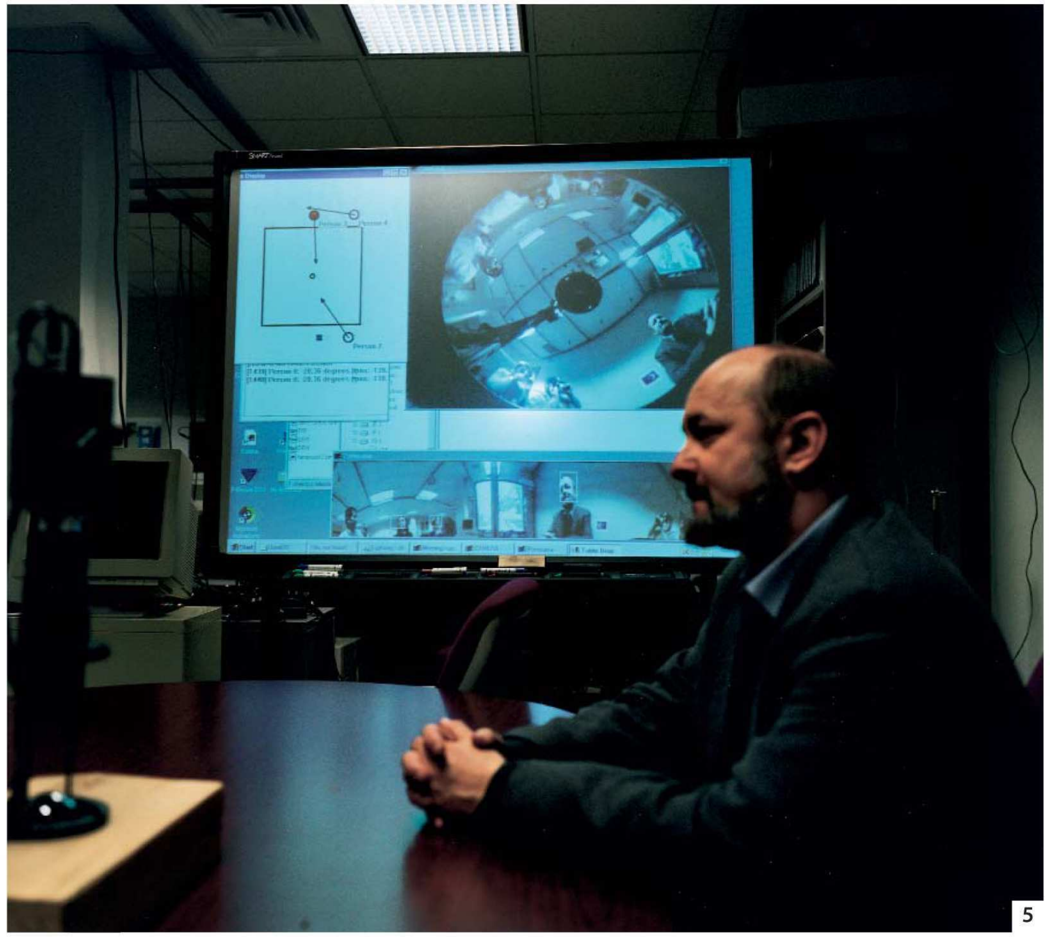
1-2. Some of the first tasks for an observant computer, Waibel says, are visual: "finding out that there are people in the room, that these people are moving, and also what are they doing." Down the hall from Waibel's office at Carnegie Mellon, research computer scientist Jie Yang's desktop computer is outfitted with a small black camera and image-processing software capable of doing just that. The computer finds *Technology Review* photo editor Lisa Petrie and Waibel in the room *(1)* and colors them red and green to mark each as unique. Yang (foreground) then poses for the camera himself *(2)*, and the software demonstrates its ability to distinguish a human face by marking Yang's eyes, nostrils, and the corners of his mouth with small white marks. "Once we have the face," Waibel says, the computer can begin to ask, "Where is the face pointing? What is the person looking at or attending to?"

3-4. To understand people, computers will also have to understand their speech—in a variety of languages—so Waibel's ideal computer might one day draw on the expertise of a handful of translation systems his lab has produced. He demonstrates the prowess of one such system—a handheld computer loaded with software that helps doctors and patients converse when one party speaks Arabic and the other speaks English.

3



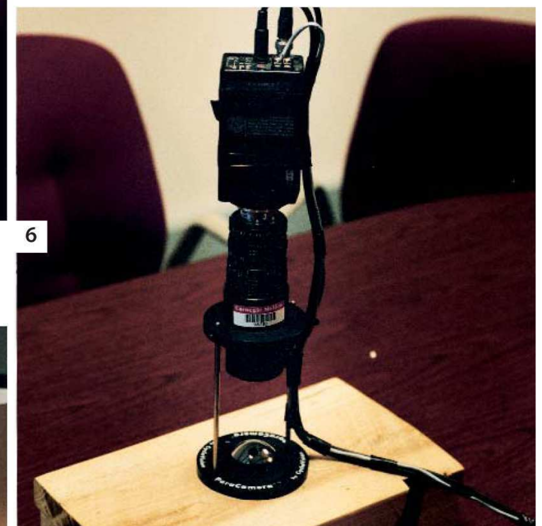
4



5

7

5-6. Waibel's most ambitious attempt to date at developing computers' powers of observation and comprehension takes the form of a makeshift meeting room. The room is rigged with microphones and a camera that sits in the center of a large conference table; the camera is aimed downward at a domed mirror, so it is afforded a simultaneous view of everybody at the table. The idea is, at first blush, a simple one: a computer will observe the meeting and act as a stenographer and assistant. "To put you in the right sense of awe of how incredibly difficult all of this is," Waibel says, "imagine at the end of the meeting, you ask a simple question of the computer: 'Why did Joe get angry at Bob when they talked about the budget?' And now imagine what knowledge you would have to have in order to answer it. First of all, you need to know that Joe was present and Bob was present. So somehow you need to do speech identification, face identification. Sec-



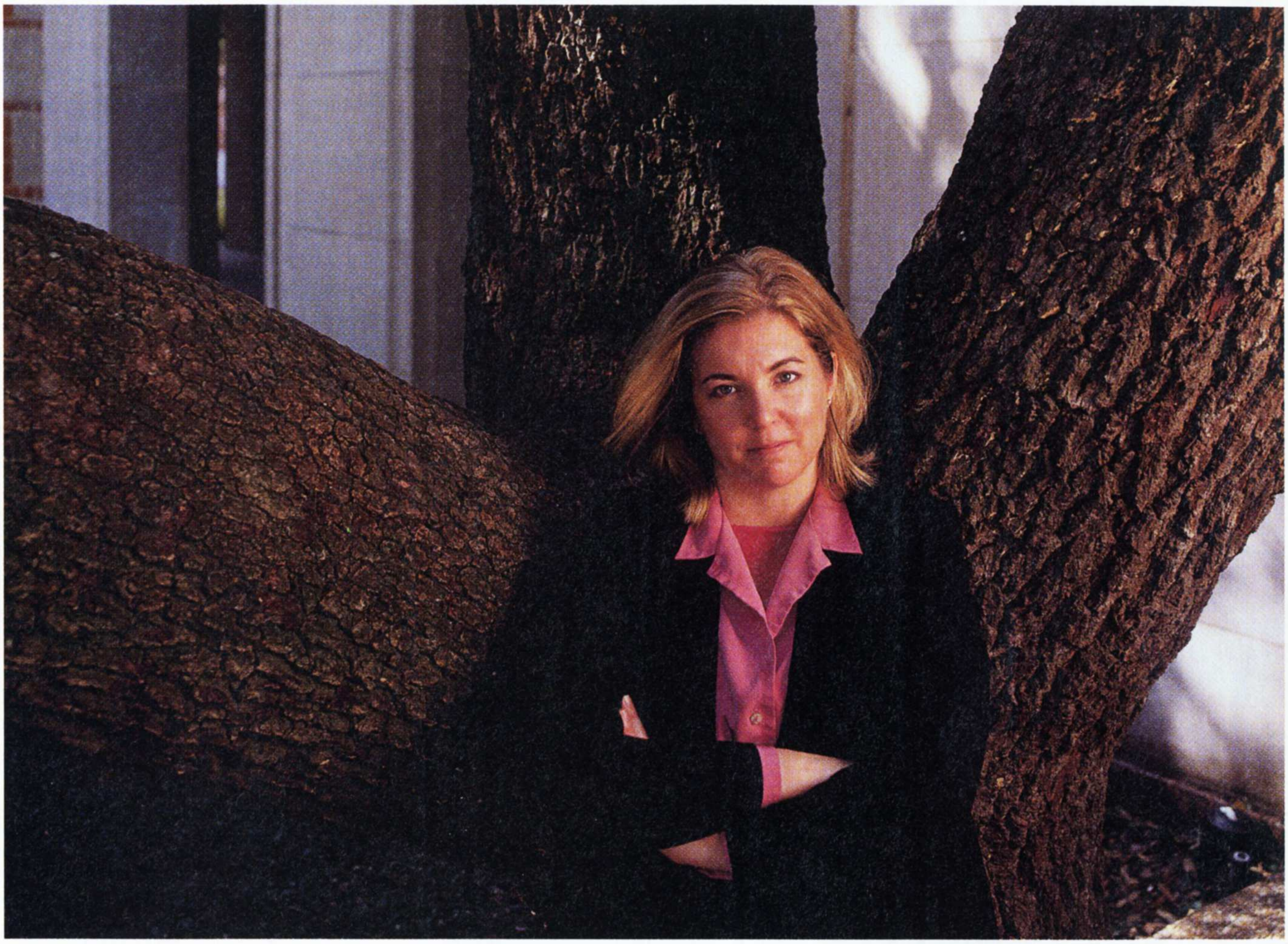
6

ond, you need to know that Joe has addressed Bob and that the emotion during that time was angry. So you need to know what the focus of attention was and that the emotion was angry and that the topic of discussion was budget."

7. Even determining that Joe is addressing Bob is more complicated than simply noting that Joe has turned his face toward Bob, Waibel says; people tend to be lazy, moving their bodies only as much as necessary to see what they want with a sidelong glance. To understand the focus of somebody's attention, he says, "we actually have a statistical model that combines head direction over time together with some notion of what potential targets of interest are—human faces and people speaking, for example." The computer, off to one side, takes in data from the microphones and camera and feeds the information into a host of such models, crunching the numbers in a valiant attempt to see, hear, and understand. TR

POINT OF IMPACT

WHERE TECHNOLOGY COLLIDES WITH SOCIETY, BUSINESS, AND PERSONAL LIVES



By David Rotman | Photograph by Wyatt McSpadden

MEASURING THE RISKS OF NANOTECHNOLOGY

Vicki Colvin

POSITION: Director, The Center for Biological and Environmental Nanotechnology at Rice University

ISSUE: The safety of nanotechnology. Do breakthroughs in nanotechnology—widely hailed for their potential in biomedicine and materials science—present unique health and environmental dangers that need to be studied?

PERSONAL POINT OF IMPACT: Colvin's nanochemistry group, which makes new kinds of nanoparticles, is beginning to work with toxicologists, biologists, and bioengineers to evaluate the unintended biological effects of these materials.

TECHNOLOGY REVIEW: Questions about the safety of nanotechnology suddenly seem to be everywhere, from Michael Crichton's bestselling novel *Prey* to calls for a moratorium on the technology by at least one environmental group. What are the chief concerns?

VICKI COLVIN: Nanomaterials are different. Because of their small size, we are able to get them into parts of the body where typical inorganic materials can't go because they're too big. There is an enormous advantage to using nanoparticles if you're engineering, for example, drug delivery systems or cancer therapeutics. This would suggest that nanomaterials that are unintentionally introduced into the body may also undergo similar processes. The concern—or the *hypothesis* would be a better way to say it—is that nanomaterials differ in their reactivity and biological availability. You can't help but ask, Well, if they are powerful biological actors, then what about unintentional consequences?

TR: Are the dangers of nanomaterials well understood?

COLVIN: It's not as if no one has ever thought about how particulate matter generally can interact with organisms. We can learn a lot from particle toxicologists who characterize the effects of aerosolized particles of all sizes on health, as well as from bioengineers who consider the effects of larger particulates generated by implants wearing down in the body. Still, specific information on the health

impacts of very small, nanoengineered particles under 20 nanometers is hard to come by. So the one thing everybody agrees on is that there just is not a lot of information out there.

Getting that information isn't going to be a simple task. Nanomaterials are incredibly diverse. You can have nanoscale carbon, nanoscale Teflon, nanoscale you name it. Within that huge diversity of materials, it would be almost amazing if all those materials were as safe as water. The toxicology data is going to start to come out, and it is almost certain that it's not going to be: nanomaterials are totally safe. Nothing in the world is totally safe.

TR: So do you expect bad news on the health effects of nanomaterials?

COLVIN: I would fully expect that within the next year there will be some concrete data on health effects. Not surprisingly, there will be some news that, hey, you can't use these materials in any possible application; you have to consider human exposure and environmental-impact issues.

From a strictly scientific perspective, there are some fascinating questions about how does the body deal with inorganic materials that are on the order of the size of hemoglobin. At this point, I think it is a mistake for someone to say nanoparticles are safe, and it is a mistake to say nanoparticles are dangerous. They are probably going to be somewhere in the middle. And it will depend very much on the specifics. But what is important is that if you're starting an industry in the area, with billions of dollars going into nanotechnology companies, you have to weigh the amazing benefits of nanotechnologies against what is right now a not well-understood risk. Is there going to be a regulatory environment to deal with? Are there going to be liability issues? The sooner we can get technical information in hand, the better.

TR: Should there be regulations on nanotechnology, the same way that we have rules for pharmaceuticals and chemicals?

COLVIN: In the next few years, the answer is no. Nanotechnology, from an industry perspective, is just now developing, and actual products for consumers are not common. But I would say once the products are developed, probably the FDA [Food and Drug Administration] should look at it. I do know that nanomaterials are already used in sunscreens and also in cosmetics. The fact that they are used in those circumstances is of interest, and I do feel that eventually there will be a regulatory component to this industry.

It is a mistake for someone to say nanoparticles are safe, and it is a mistake to say nanoparticles are dangerous. They are probably going to be somewhere in the middle. And it will depend very much on the specifics. The sooner we get the technical information in hand, the better.

TR: Have the nanoparticles used in sunscreens and cosmetics been tested? What do you tell people about the risks of these consumer products?

COLVIN: To my knowledge, they have not been tested. Do I use sunscreens? Yes. Does it make me stay up at night? Actually, it doesn't. Because the kind of diseases—if you look at other larger particulate-based diseases—are ones that usually develop in workers who have acute exposures to the materials over decades. So I don't feel that there is any chance occasional sunscreen use is unhealthy for me or my family. Still, it would be better for everyone to conduct thorough tests.

TR: Since nanoparticles are so small, can they go anywhere in the body?

COLVIN: It is known that under the right circumstances nanoparticles can go into cells. This fact alone isn't a cause for concern. Although the data is not systematic, below about 50 nanometers [about the size of a cold virus] they definitely tend to go in. Then, the question is: Where do

they go? How do they distribute in the body? And the data on that is a little bit less clear. Smaller particles apparently circulate for much longer and in some cases can cross the blood-brain barrier. And they can certainly leak out of capillaries and get into the fluids between cells. So they can go places in the body that your average inorganic mineral can't.

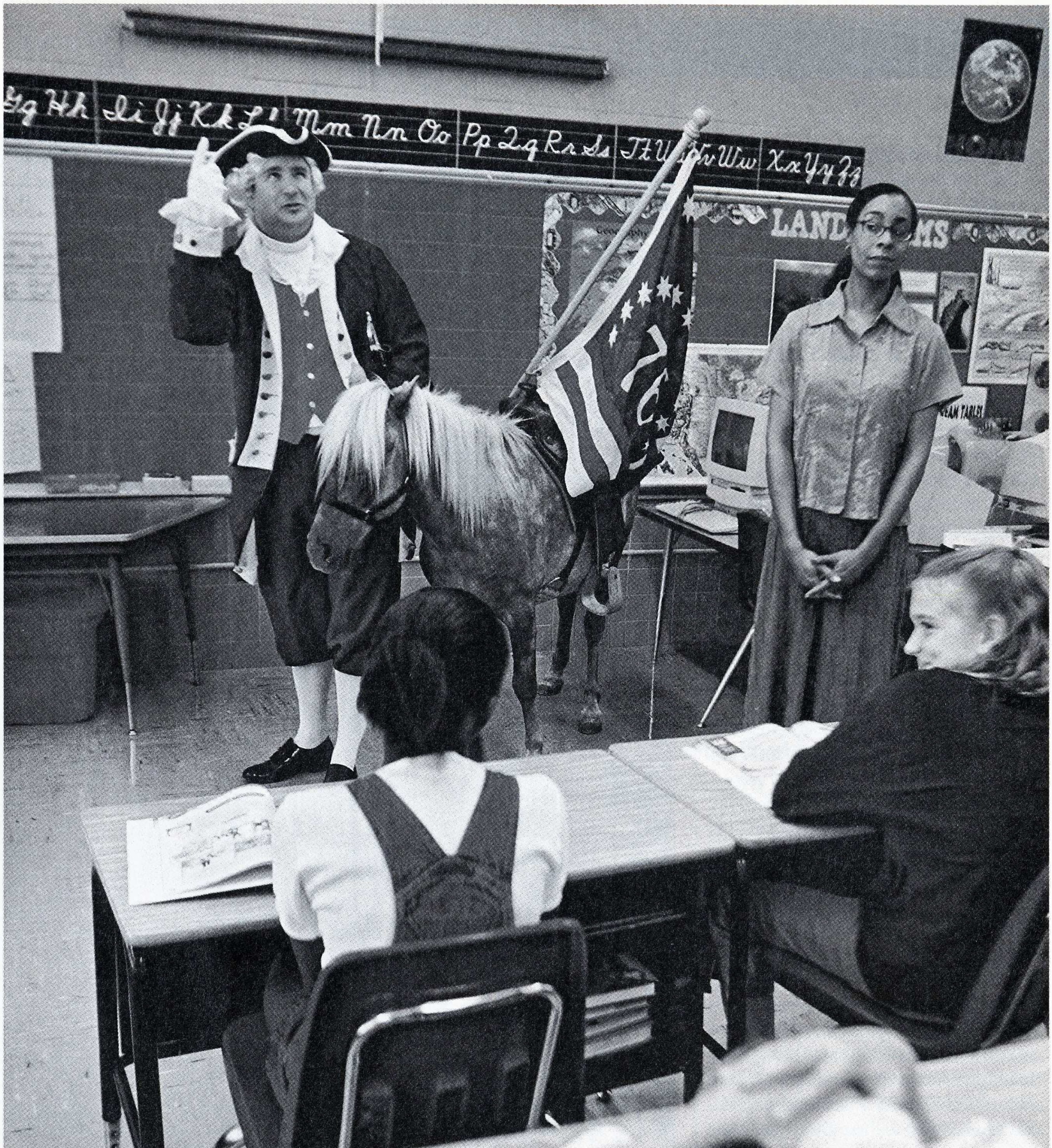
TR: Are there any areas where you feel efforts in nanotechnology should probably slow down?

COLVIN: New types of solar cells or new methods for treating cancer, to take just two examples, offer amazing benefits to our society that outweigh any speculation about risks. I am less convinced that nanomaterials used in cosmetic products are worth the risk.

TR: Are you worried that public fears will hinder the development of nanotech?

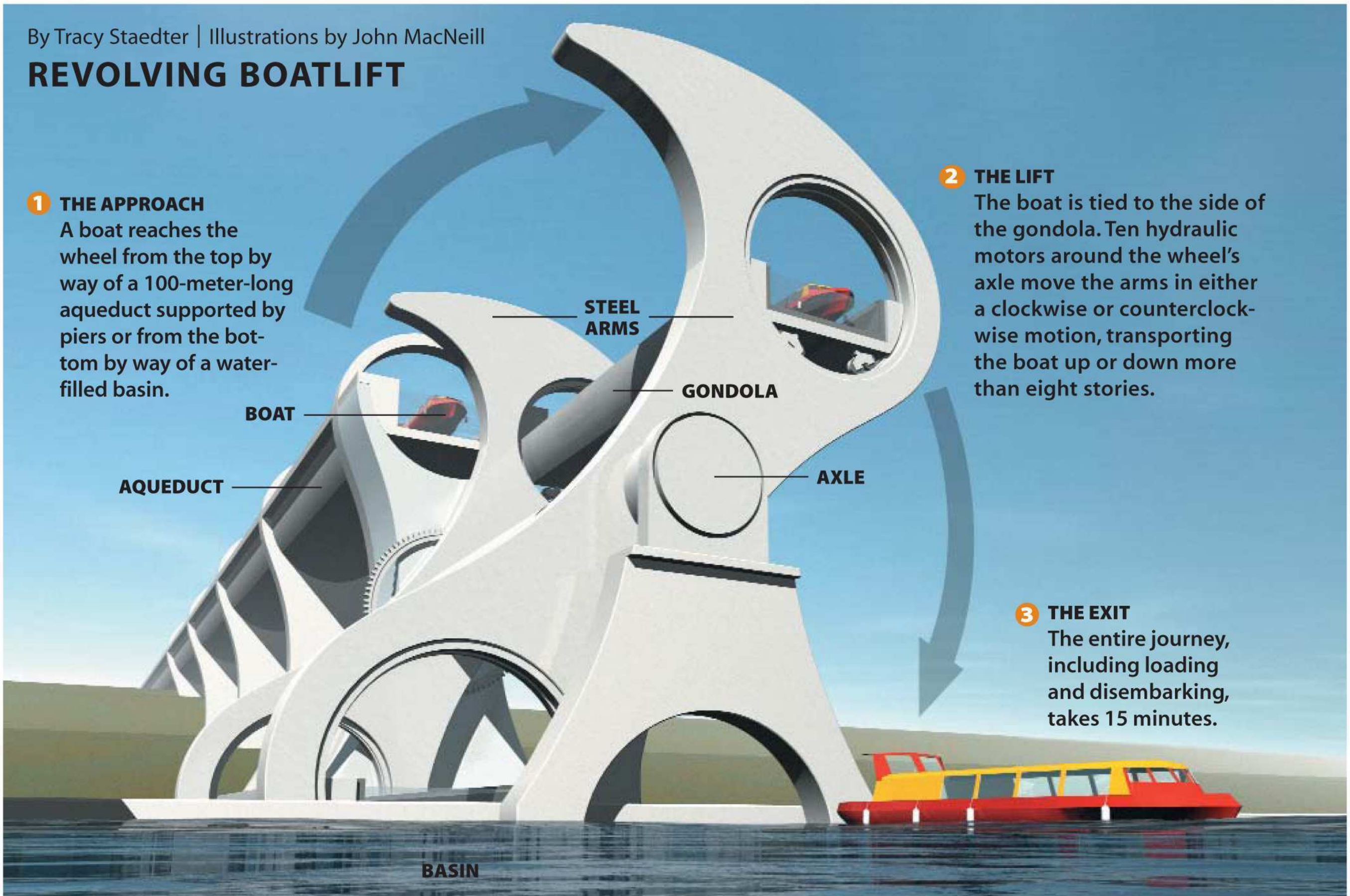
COLVIN: Ultimately, people have to make a cost-versus-benefit decision. The benefits of nanotechnology are well recognized by scientists and our federal government, which has put over a billion dollars into the area. But there will almost certainly be costs to implementing nanotechnology. To try to stick your head in the sand and say, Oh no, all of nanotechnology will only result in perfectly safe and good technologies is simplistic. A number of very powerful organizations like Greenpeace, specifically the ones that went after genetically modified organisms, are beginning to look at nanotechnology. As a technical person, you have to listen to these groups and take their fears seriously.

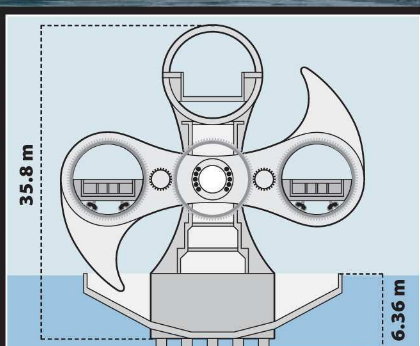
If it were a perfect world, we wouldn't think about this topic for 10 years. And then all the data would be there, and we would make a good decision. But the fact of the matter is that society will be forced to make a decision in the absence of data. I don't know what the technical answers are yet. I can only tell you that it is a very diverse and complex problem. There are going to be a lot of different answers. And, yeah, I'm anxious about when that first paper on the health effects of nanomaterials publishes. TR


Want to help your kid with history but not sure how?
Learn how to encourage curiosity, how to raise a reader, and what you can do at home to help your child in school. For all kinds of ways to help all kinds of kids, log on to
www.connectforkids.org
Ad Council
nea
NATIONAL EDUCATION ASSOCIATION

By Tracy Staedter | Illustrations by John MacNeill

REVOLVING BOATLIFT





In the past, boaters passing between the Forth and Clyde and the Union canals had to wait as long as six hours for 22 lock gates to open and close. Today that journey covers the distance in one five-minute-long arc through the air.

It resembles an amusement park ride, but the Falkirk Wheel in Falkirk, Scotland, is the world's only revolving boatlift. It opened in May 2002, and now performs a task that previously required 11 locks: moving boats along the 35 meters of vertical height between the Forth and Clyde and the Union canals.

Although it's called a wheel, the Falkirk is not round. It consists of two large, identical steel arms 28 meters apart, which rotate on an axle speared though their centers. The arms support two 26.5-meter long, water-filled tubs, or gondolas—one at the top and one at the bottom.

A 30-centimeter gap between the gondola and the end of the waterway must be filled with water before a boat can enter. Bellows-like seals expand to form a watertight connection between the waterway and the gondola. A valve allows water to fill the gap. When the water levels inside and outside the gondola are even, doors open, allowing the boat to enter. The doors close, and pumps drain the water from the gap. The wheel is then free to turn.

The Falkirk Wheel's stats are Herculean. The twin arms with their gondolas weigh a combined 1,300 metric tons. Each gondola carries about 250,000 liters of water and can accommodate as many as four 10-meter boats. Boaters at the top have a 50-kilometer view of the countryside. In fact, it's the only place where the best view of Scotland is from the helm of a boat. TR

For an animated version of this illustration, go to www.technologyreview.com/visualize/.

SOURCE: BUTTERLEY

Do you know how fast you were going?

Our man is a top industrial designer of fast Italian sports cars. His designs go way beyond functional. They are truly considered to be an art form. One of the most beautiful experiences for any automobile connoisseur is staring at one of our man's dashboard designs on a rarefied Italian speed demon. White dials …illuminated hands …and a brushed steel casing.

He has now designed a watch based on these cockpit designs. This chronograph has separate white dials for the the 60 second stop watch, the minute and hour timers—making it reminiscent of the tach and speedometer on a 12-cylinder monster. Finally, a serious sports watch priced like an good Italian Dinner, not a trip to the Italian Grand Prix. Watches of similar quality sell for $700 to $1000.

The Moretti Chronograph appears to be revving at 5000rpm and driving through a chicane at 130 mph but without the added expense of the gas, oil and changing four new tires in the pit. The hands are luminous so that they can be seen in low light and the watch is water resistant to 5 atms. So feel free to wear it swimming off the coast of Corsica. The Italian designs are gorgeous but we were smart enough to add a super reliable quartz movement from Japan into this chronograph. Italian design and Japanese reliability. Now if we could find an English butler and a French chef, life would be quite fine indeed.

The Moretti comes with a no questions asked 30 day guarantee. Wear it on your wrist for a month and if you do not completely love it send it back for a full refund of the purchase price. Oh… and by the way, we will not be held responsible for any speeding tickets received while wearing this chronograph.

Not Available in Stores

Call now to take advantage of this limited offer.

Moretti Chronograph ~~$299~~ **$179.95** +S&H.

800-859-1542

Be sure to mention promotional code MRW101 when you call.

To order by mail, please call for details.

NEXTTEN
products for your next ten years.

14101 Southcross Drive W., Burnsville, MN 55337

For fastest service, call toll-free 24 hours a day **800-859-1542**

BIG IVORY TAKES LICENSE

IBM did some justifiable crowing recently when official government tallies confirmed that for the 10th consecutive year, it had garnered more U.S. patents than any other company on the planet, adding 3,288 patents to its collection in 2002. IBM says its massive patent portfolio has generated roughly $10 billion in licensing revenues over the past decade.

The numbers are impressive, but even more noteworthy is IBM's open licensing policy: Big Blue makes nonexclusive licensing deals with just about anyone willing to pay for access to its technology. The strategy has served the company well over the years. IBM won big, for instance, when it nonexclusively licensed its seminal patents on the personal computer and PC "clones" flooded the marketplace. Such PC powerhouses as Dell, Gateway, and Compaq—to name a few licensees—owe their very existence to this policy. And IBM has enjoyed a healthy stream of licensing revenues.

But let's compare Big Blue's record to that of another esteemed U.S. engine of innovation—one we might call Big Ivory.

I'm talking, of course, about the U.S. universities and nonprofit research institutions that make up the proverbial ivory tower. According to the most recent figures available from the Association of University Technology Managers, Big Ivory garnered 3,598 U.S. patents in fiscal year 2000 (compared with IBM's 2,886 that calendar year). With those patents alone, Big Ivory generated $1.24 billion in licensing revenues—in the same ballpark as the "more than $1 billion" reported by IBM during that time. Here's the rub: in stark contrast to IBM, roughly half of Big Ivory's licenses are granted on an exclusive basis. In other words, universities regularly make deals in which a single company gains complete control over a patented technology.

Some technology-licensing managers at universities argue that exclusive arrangements are the only way to bring embryonic technologies to market. In theory, that's a sound argument. It makes sense for a university to grant exclusivity to a startup that is founded specifically to bring a particular bit of research to market. (Some 90 percent of such arrangements with universities are exclusive deals.) But startups aren't the only beneficiaries. Figures from the university technology managers show that more than one-third of the technology licenses academia grants to large, established companies are exclusive deals as well. This is bad technology policy.

Exclusive technology licenses go against the ethic of openness that has helped build U.S. universities into research powerhouses. The terms of most of these arrangements are tightly guarded secrets. No doubt the practice is driven by the fact that exclusive licensing deals boost the up-front payments industry partners are willing to make. But considering that U.S. taxpayers fund nearly two-thirds of Big Ivory's research, we need to think about more than just the short-term payoff. Even IBM recognizes that exclusive licenses can block innovation. And that's an outcome that runs counter to the public interest.

Perhaps the most powerful example of such untoward results is the notorious CellPro case. The case was resolved back in 1998, but it is brilliantly reexamined and analyzed in all its sorry detail in the latest issue of the *Milbank Quarterly*, a health policy journal. Authors Avital Bar-Shalom and Robert Cook-Deegan—the first, a fellow at the American Association for the Advancement of Science; the second, the director of the Center for Genome Ethics, Law, and Policy at Duke University—detail the potential pitfalls of exclusive university licensing.

The CellPro case centered on a bitter fight over a technology for isolating stem cells from bone marrow; the technology can be used in cancer treatment. Cell separation technology developed at Johns Hopkins University—with funding from the National Institutes of Health—was exclusively licensed to Chicago-based biomedical giant Baxter International. Around the same time, CellPro, an innovative Seattle-based startup, developed a related technology and beat Baxter to the market by two and a half years with a government-approved technology for treating advanced cancers.

Universities regularly make licensing deals that give one company exclusive control over emerging technologies developed at taxpayer expense. Reform starts by making academia disclose such deals.

In the late 1990s, brandishing its exclusive license from Johns Hopkins, Baxter went to court. By that time, CellPro's device was in widespread use: the treatment of some 5,000 dying patients at 300 hospitals was hanging in the balance. But Baxter's exclusive license from Big Ivory forced CellPro into bankruptcy when it lost the patent lawsuits. "It's disturbing that an exclusive license from a publicly funded research institution could effectively block innovation, but the CellPro case illustrates this quite starkly," Cook-Deegan says. "In this case," he adds, "the laggard innovators won."

Cook-Deegan cautions against drawing sweeping conclusions from one case study. But there can be no doubt that the pervasiveness of exclusive licensing is stymieing innovation, and it is just a matter of time before the next CellPro debacle arises.

What's the answer? The first step is to let in some sunshine. The Bayh-Dole Act of 1980 allows universities to license their patents without publicly disclosing the deals they make. Disclosure can arm policymakers with the information they need to foster wide dissemination of publicly funded emerging technology. As Cook-Deegan puts it, taxpayers "should know what's happening with the intellectual property they pay to create." It's not often you'll catch me saying this, but here it's true: what's good for IBM is good for the country.

INDEX

PEOPLE AND ORGANIZATIONS MENTIONED IN THIS ISSUE

PEOPLE

ORGANIZATIONS

CLASSIFIEDS

The Universal Product Code was launched at a Marsh Supermarket in Troy, OH, in June 1974.

COURTESY OF THE NCR ARCHIVE AT THE MONTGOMERY COUNTY (OH) HISTORICAL SOCIETY

BEHIND BARS

The inventors of the first linear bar-code system were decades ahead of their time

More than five billion bar codes are scanned each day worldwide, and that number is increasing rapidly as the codes' uses extend beyond the checkout counter. Although bar codes are fast becoming ubiquitous, Norman Joseph Woodland, who patented the idea of a linear bar-code system in 1952, had to wait more than 20 years to see the system in action. His coinventor, Bernard Silver, didn't live to see it at all.

In 1948 the president of a grocery store chain in Philadelphia implored a dean at Drexel Institute of Technology to develop an automated checkout system. Silver, a graduate student, overheard the conversation and was instantly intrigued. Woodland, a friend and fellow grad student, shared Silver's enthusiasm, and the two devoted themselves to the effort. In late 1949 they applied to patent a system that drew on aspects of Morse code and movie sound systems. Similar to today's bar code scanners, their device used a light source and a photosensitive reader to translate data encoded in linear symbols. But because it required a blindingly bright, extremely hot 500-watt incandescent light bulb and a large, unwieldy vacuum-tube photomultiplier to process data, the invention wasn't appealing for widespread use in grocery stores.

The two inventors were undeterred. Their patent was granted in 1952, and Woodland hoped to continue to improve the system at IBM, where he had recently taken a job. The company expressed only limited interest in Woodland and Silver's work, and after several years the two sold the patent to Philco and turned their attentions elsewhere. Silver died in 1962.

In the late 1960s just as Woodland and Silver's patent expired, several nascent technologies converged to make product-scanning systems feasible. The laser could provide an intense, low-heat light source, and processors were becoming small and inexpensive enough for commercial use. Several companies demonstrated prototype systems, causing quite a stir in the grocery industry. Ten grocery manufacturers and retailers formed a committee in 1970 to choose a standard for encoding product data.

By then, IBM wanted in on the action, and it brought in Woodland, who was still at the company, to help launch a bar code research effort. In the spring of 1973 the standards committee chose IBM's symbol, designed by engineer George J. Laurer, over those from six other companies. On June 26, 1974, in Troy, OH, a package of Wrigley's chewing gum was the first item scanned using the Universal Product Code. —*Lisa Scanlon*

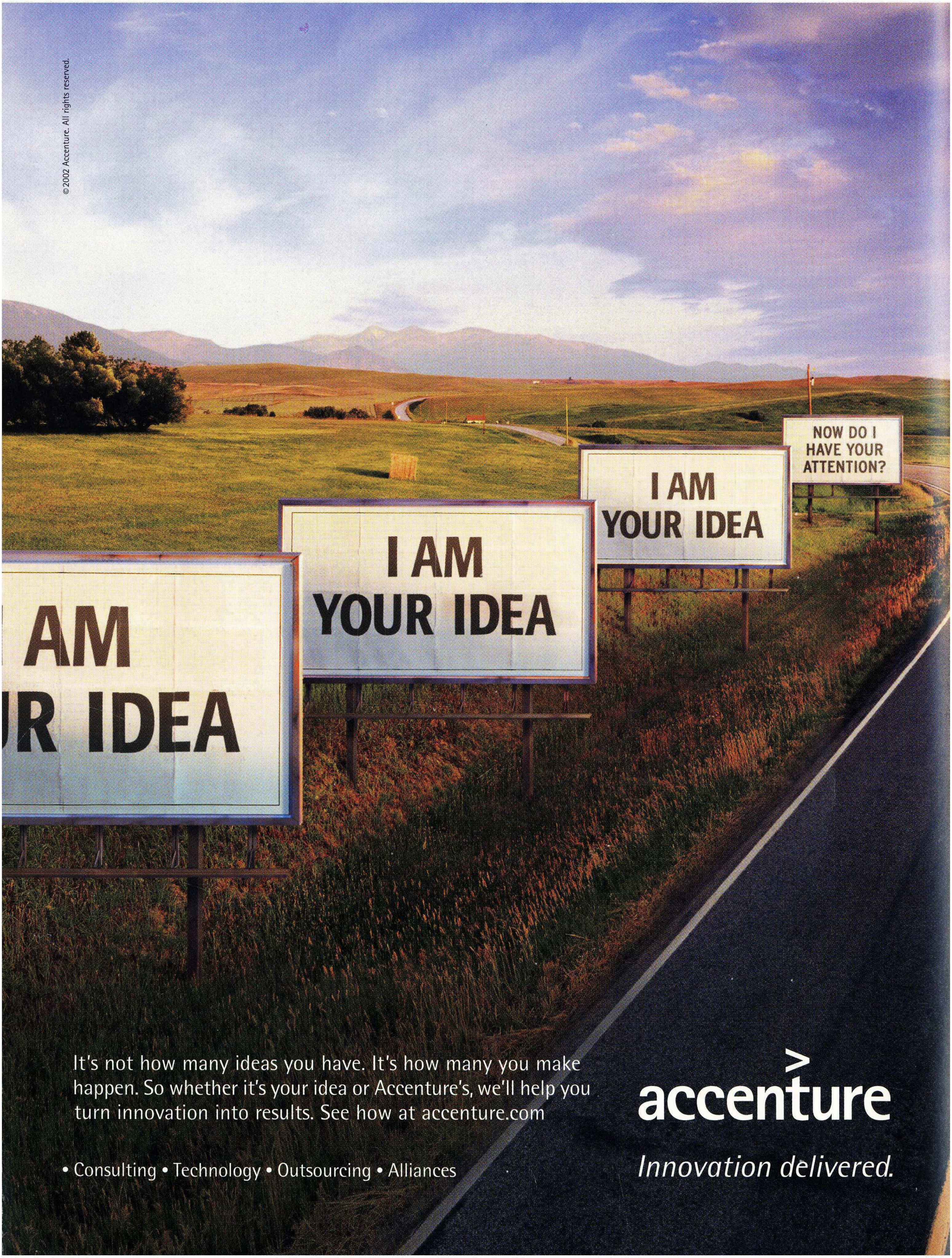
Technology Review (ISSN 1099-274X), Reg. U.S. Patent Office, is published monthly, except bimonthly in December/January and July/August, by the Massachusetts Institute of Technology. Entire contents ©2003. The editors seek diverse views, and authors' opinions do not represent the official policies of their institutions or those of MIT. Printed by Brown Printing Company, Waseca, MN. Periodicals postage paid at Boston, MA, and additional mailing offices. Postmaster: send address changes to *Technology Review*, Subscription Services Dept., PO Box 420005, Palm Coast, FL 32142 , or via the Internet at www.technologyreview.com/customerservice/. Basic subscription rates: $34 per year, Canadian residents add $10, other foreign countries add $30. Publication Mail Agreement Number 40621028. Send undeliverable Canadian copies to PO Box 1051, Fort Erie, ON L2A 6C7. Printed in U.S.A.
ABC audited

Can your antivirus software provide double the scanning power? Ours can.

Making sure your company is secure gets more and more difficult every day. That's why *e*Trust™ Antivirus v7 from Computer Associates uses dual scanning engines to ensure comprehensive virus protection. It processes data in real time to search out and eliminate viruses, and it also scans files during prescheduled and off-peak hours. All at the cost of most single-engine AV products. It's more than just twice the protection. It's twice the peace of mind.

ca.com/etrust/antivirus

*e*Trust™ Antivirus ca Computer **Associates**®



© 2002 Accenture. All rights reserved.
I AM YOUR IDEA
I AM YOUR IDEA
I AM YOUR IDEA
NOW DO I HAVE YOUR ATTENTION?
It's not how many ideas you have. It's how many you make happen. So whether it's your idea or Accenture's, we'll help you turn innovation into results. See how at accenture.com
• Consulting • Technology • Outsourcing • Alliances
accenture
Innovation delivered.